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COST CHARACTERISTICS OF TILT-ROTOR, CONVENTIONAL AIR AND HIGH SPEED  
RAIL SHORT-HAUL INTERCITY PASSENGER SERVICE

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## SUMMARY

This report describes in detail the cost analysis done to support an assessment of the potential for a small (approximately 45-seat) tilt-rotor aircraft to operate in short-haul (300 miles or less) intercity passenger service. Anticipated costs of tilt-rotor air service were compared to the costs of two alternatives -- conventional air (represented by the DC-9) and high speed rail (represented by the Metroliner). Costs were developed for corridor service, varying key market characteristics including distance (between end point cities), passenger volumes (up to 1500 passengers per day in each direction), and minimum frequency standards. The resulting cost vs. output information can then be used to compare modal costs for essentially identical service quality and passenger volumes or for different service levels and volumes for each mode, as appropriate. Extensive sensitivity analyses are performed.

The final section of this report contains a brief comparison of the cost-output features of these technologies. Tilt-rotor is very attractive compared to high speed rail (HSR) in terms of costs over the entire range of volume. It also has costs not dramatically different from conventional air (CTOL) -- but tilt-rotor costs are generally higher. Thus some of its other advantages, such as the VTOL capability, must offset the cost disadvantage for it to be a preferred or competitive mode in any given market. These issues are addressed in the companion report which considers strategies for tilt-rotor development in commercial air service.

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SYMBOLLIST OF DEFINITIONS

ACTI	The annual cost of fleet investment, \$/yr.
AFH	Annual flight hours, aircraft hrs./yr.
AMB	Annual cost of aircraft maintenance burden, \$/yr.
APRK	Annual cost for investment for aircraft parking area, \$/yr.
APRKM	Annual cost for maintenance for aircraft parking area, \$/yr.
AR	Bi-directional number of daily aircraft flights during peak periods, departures/peak periods-day
ASPT	Annual cost of assistant superintendant, \$/yr.
ATAAC	Average cost per passenger (total cost), \$/pass
ATALC	Average cost per passenger (total cost minus all fixed capital cost), \$/pass
ATALCA	Average cost per passenger (total cost minus all capital cost), \$/pass
BI	Total number of terminals in the system, terminals
BNSP	Annual number of passengers on system, passengers/yr.
BNTR	Number of aircraft or trains required for service on system, vehicles
BP	Number of base period hours each day, hours/day
BPHP	Bi-directional daily passenger volume during both peak periods, pass/peak periods - day
BPP	Bi-directional daily passenger volume during base period, pass/base period - day
BS	Annual cost of block station, \$/yr.
BUTC	Bi-directional total car volume, cars/day
CAP	Bi-directional daily passenger volume, pass/day
CLEN	Annual cleaning expense for terminal, \$/yr.
CM	Annual car miles, car miles/yr.
CMISC	Annual miscellaneous cost, \$/yr.
CND	Number of cars needed for operation of service, cars
CRF	Capital recovery factor, \$/\$

### DEFINITIONS

CTOL	Conventional take-off and landing aircraft (designation)
DFREQ	Total daily two-way frequency on system, departures/day
DM	Annual cost of direct maintenance, \$/yr.
DME	Annual cost of maintenance for vehicles, \$/yr.
DMWS	Annual cost of maintenance of way and structures, \$/yr.
DO	Annual cost of division operators, \$/yr.
DOFR	Daily two-way frequency on system during the base period, departures/ base period-day
DPFR	Daily two-way frequency on system during the total peak period (both morning and evening peak together), departures/peak periods-day
EP	Cost of electric power, \$/yr.
FC	Annual cost of flight crews, \$/yr.
FDI	Annual cost for flight deck investment, \$/yr.
FDM	Annual cost for maintenance of flight deck, \$/yr.
FO	Annual cost for fuel and oil, \$/yr.
GA	Annual cost for gate area investment, \$/yr.
GAM	Annual cost for maintenance of gate area, \$/yr.
GFC	Annual general fixed cost, \$/yr.
GTM	Annual gross ton miles, ton-miles/yr.
GVC	Annual general variable cost, \$/yr.
HI	Hull insurance, \$/yr.
HSR	High speed rail (designation)
NCAR	Number of coach cars in train of maximum length, cars
OAR	Bi-directional number of daily aircraft flights during the base period, departures/base-period-day
OCAP	Number of daily usable seats during the base period at the given specified load factor, seats/base period-day
OFR	Unidirectional daily frequency during the base period, departures/ base period-day
OHD	Base period headway, hr./departure
PCAP	Number of usable seats during the daily peak period hours, seats/peak periods-day

## DEFINITIONS

PERC	Personnel cost at central office building, \$/yr.
PFR	Directional frequency during the daily peak periods, departures/ peak periods-day
PH	Number of peak hours during the day, hours/day
PHA	Annualized cost of the urban terminal passenger handling area, \$/yr.
PHAM	Annual cost for maintenance of terminal passenger handling area, \$/yr.
PHD	Peak hour headway, hr./departure
PHP	Number of passengers on system during each peak hour, pass/hr.
PPCUU	Cost per passenger mile (total cost considered), \$/pass-mi
PPRK	Annual cost for passenger parking area, \$/yr.
PPUUV	Cost per passenger mile (total direct cost considered), \$/pass-mi
PPWOV	Cost per passenger mile (total direct cost minus fleet investment cost), \$/pass-mi
SCAR	Number of snack cars on train of maximum length, cars
SFC	Annual suburban fixed cost, \$/yr.
SL	One-way stage length of link, miles
SMA	Annual cost of station master, \$/yr.
SMAIN	Annual cost for maintenance of terminal, \$/yr.
TAAC	Total annual cost for operation of aircraft system, \$/yr.
TALC	Total annual cost less all cost from capital expenditures not including vehicles, \$/yr.
TALCAV	Total annual cost less all cost from capital expenditures, \$/yr.
TAM	Total annual flight miles, miles/yr.
TAPRK	Total annual cost for aircraft parking, \$/yr.
TAROPA	Terminal expenditures not due to capital expenditures (all terminals), \$/yr.
TDOC	Total direct operating cost, \$/yr.
TER	Annual cost to upgrade track, \$/yr.
TERCA	Total annual cost for all terminals, \$/yr.
TERCE	Total annual cost for each terminal, \$/yr.



### DEFINITIONS

TERCOS	Total terminal cost (passenger and capital expenditures), \$/yr.
TEROPE	Terminal expenditures not due to capital expenditures (each terminal), \$/yr.
TERPAX	Terminal cost for each passenger in system, \$/yr.
TIOC	Total indirect operating cost, \$/yr.
TMAX	Total number of seats on train of maximum length, seats/train
TMD0	Number of usable seats on a train of maximum length during the base period, seats/train
TMDP	Number of usable seats on a train of maximum length during both peak periods. seats/train
TRC	Annual cost of train crews, \$/yr.
TSTAF	Total annual cost for terminal staff, \$/yr.
TT	Total vehicle cycle time (from departure at point A until next departure at point A), hours
TUUC	Total annual cost, \$/yr.
UAR	Directional daily aircraft volume during peak periods, departures/day
UBPP	Directional daily passenger volume during the base period, pass/day
UCT	Cars per train during the peak period, cars/train
UFC	Total annual urban fixed cost, \$/yr.
UOAR	Directional daily aircraft volume during base periods, departures/day
UOCAP	Directional usable seat volume during the daily base period, seats/day
UOCT	Cars per train during base period, cars/train
UPCAP	Number of usable seats during the daily peak period, seats/day
UPHP	Directional passenger volume during the daily peak periods, pass/day
UTC	Directional car volume, cars/day
UTFREQ	Directional frequency on the link, departures/day

### DEFINITIONS

UTIL	Annual cost of utilities for the terminal, \$/yr.
UTSO	Annual cost for urban ticket sales operation, \$/yr.
UUF	Annual fixed cost, \$/yr.
UUV	Annual variable cost, \$/yr.
UUVWOV	Annual variable cost excluding vehicle cost, \$/yr.
UVC	Annual urban variable cost, \$/yr.
VTOL	Vertical take-off-and-landing aircraft (designation)
YAS	Annual yard and switching cost, \$/yr.

## 1.0 INTRODUCTION TO COST MODELS

### 1.1. OBJECTIVE

One basic criteria for acceptance of tilt-rotor aircraft into the commercial air system hinges on its economic feasibility. The potential opportunities for replacing existing technologies or creating new markets depend in part on how competitive tilt-rotor costs are. Therefore, models estimating costs vs. transportation output (passenger traffic carried and service quality) were developed for tilt-rotor technology and two other short haul intercity passenger transport technologies -- one representing conventional air and the other high speed rail. The following technologies were analyzed:

1. VTOL aircraft (with CTOL capability): 45 passenger tilt-rotor
2. CTOL aircraft: McDonnell Douglas DC-9-30
3. High speed passenger rail: electric Metroliner type trains

While other air and rail designs could have been used, resources limited the analysis to three technologies and these were judged to be good representations of their respective classes.

The costing procedures used conform to the respective modal industry standards. For example, the direct and indirect operating cost component categories of the air modes comply with those normally used by the airline industry. For the rail mode, the cost components are fixed and variable cost categories corresponding to the usual cost categories of that industry. Although the cost components are not directly comparable between the modes, various overall cost comparisons can be made with these models. The main focus of the comparison is on three separate average annual costs per passenger mile, which are based on the following overall costs:

- 1) Total cost: All costs incurred in providing the service (i.e. both capital cost and cost incurred by performing the service of moving passengers).
- 2) Total costs minus all fixed facility costs: Cost for maintenance of capital structures and facilities are still included in this cost.
- 3) Total cost minus all capital costs: This is the same cost as number 2 above except vehicle investment cost are now excluded.

The rationale for the use of total cost is clear; this represents the usual measure of cost that would actually be incurred by the operator of a service with the customary arrangements for cost responsibility in our society. Of course, this cost does not include externalities such as the costs of aircraft noise pollution or train-induced ground vibration. This is the most commonly used cost for comparison purposes, with other relevant factors such as externalities treated separately.

Total cost less fixed facility cost is calculated as well for two reasons. First, some persons argue that since road and air facilities are provided by government, financed partly out of general tax revenues, a useful mechanism by which to make all modal costs comparable is to delete fixed facility costs entirely. While this logic is fallacious for many reasons (e.g., road and air facility users do pay user fees covering at least part of the facility costs), such cost comparisons are often made and it is often useful in modal comparisons to ascertain whether or not the relative performance of modes would vary depending on the cost measure used. A second reason is that air facility charges are often far less than fully allocated costs (partly because of cross-subsidy allowed by surplus auto parking revenues, for example), and it is useful to ascertain what air carrier costs would be with "underpriced" airport costs; excluding all fixed facility costs provides a lower bound on this.

The third cost covers only operating (and maintenance) costs. These are of general interest for a variety of analysis purposes, probably mainly because they are often taken as a measure of short-run marginal costs.

## 1.2. METHODOLOGY

The specific objectives for each of the cost models include the following:

1. Investigate in depth the full cost elements associated with each of these intercity passenger modes of transportation and develop cost relationships for each of the major elements contributing to total cost.
2. Explore the variation in cost of providing transport service with each of these modes as a function of variations in the characteristics of the market to be served, such as total traffic flow or length of route.
3. Provide information on the sensitivity of cost within each mode to variations in the cost of components, especially those which are uncertain.

The general approach to the development of cost and performance models follows that described in the book E. K. Morlok, An Analysis of Transport Technology and Network Structure, 1970. Many of the relationships and parameters employed in this model are from the follow-up 1972 DOT report by Bolusky et al., on short-haul intercity passenger carriers, their costs and service characteristics, which was used extensively for this report. Much of the information directly applicable to tilt-rotor aircraft was taken from the 1975 NASA report, "Conceptual Engineering Design Studies of 1985 - Era Commercial VTOL and STOL Transports that Utilize Rotors." Considerable information applicable to the DC-9-30 was taken from the 1983 report "Aircraft Operating Cost and Performance Report." Additionally, much information was obtained from direct contact with individuals in the aircraft and rail passenger industries.

### 1.3. ASSUMPTIONS

In computing the levels of output associated with each technology certain assumptions were made. One major assumption was that passenger traffic volumes are equal in both directions on the link. This assumption cannot be altered unless major revisions are made to the model.

Most of the other assumptions can easily be altered by changing a single entry in the data file or program. These include the following, grouped by those pertaining to costs, service quality and capacity, and operations/technology.

#### Costs

1. All costs of building and maintaining the system are incurred by the operator. For CTOL aircraft, landing fees are charged but no additional costs were assessed for capital investment of runways and terminals. However, maintenance of these facilities are still applicable and were accounted for. For VTOL aircraft operations, it was assumed that a landing area and terminal area had to be constructed. However, it was assumed that no land had to be acquired. For the most part, VTOL aircraft were assumed to operate primarily from existing airports or from major activity centers where land would be made available. For the rail mode, it was assumed that existing urban terminals were being used, which represent a sunk cost.

2. The interest rate used is 15% per annum.

#### Service

3. Level of service characteristics are similar for each mode. The system consists of two nodes separated by a single link of varying stage length. There are no intermediate stops on the link, as all service is non-stop.

4. The operating day for a passenger system is considered to be 16 hours long. The day starts with the first departure of a carrier in the morning and ends with the last departure in the evening. Intercity passenger

traffic slacks off considerably during the evening hours and does not pick up until about 6 or 7 A.M. each morning. Two two-hour peak periods are assumed. These occur from 7:00 A.M. to 9:00 A.M. and again from 4:00 P.M. to 6:00 P.M.

5. Minimum headways in each direction are as follows unless noted otherwise: peak period: 1 hour; base period: 2 hours.

6. Snack and/or beverage service and lavatory facilities are provided; seat pitch and width are similar and only coach seating is used.

7. The number of peak hour passengers equals 10% of number of daily passengers. The basis of this assumption is found in the demand studies section of the main report of the 1972 DOT report. It appears that an average of 10% of the number of daily passengers travel in both peak periods combined.

8. The maximum average load factors for the cost model computation are assumed to be 50% for base period operations and 80% for peak period operations. These figures were chosen as representative of travel flows in short haul intercity corridors, and represent maximum load factors in this analysis. Load factors vary with the time of the day, but do not vary with the stage length.

9. It is assumed that the service is provided 365 days a year.  
Operations

10. The average cruise speed for the VTOL aircraft was assumed to be about 260 mph, for the DC-9-30 aircraft about 325 mph.

11. The capacity for the tilt-rotor aircraft is 45 passengers and for the DC-9-30 aircraft, 115 passengers.

12. Rail train capacity is varied to suit passenger loads, up to a maximum of 10 cars. Train maximum cruise speed is 120 mph, with the average speed being 100 mph. Rail line length is assumed to be 14% longer than the great circle (air) distance, reflecting average U. S. rail circuitry.

13. Turn-around times were determined by research performed in the 1972 DOT report. In determining turn-around time, certain specified services were considered to have been performed on the vehicle. Service common to all vehicles during the time they are at the terminal include passenger debarking and embarking, baggage handling (air mode only), passenger compartment cleaning, and vehicle fueling. The minimum turn-around times used for the air modes were 20 minutes at each terminal, and the minimum time for rail was one hour.

#### 1.4. COST AND RELATED DEFINITIONS

Fixed and Variable Cost; In the context of this report fixed costs are considered to be long run fixed costs and include capital expenditures for items such as buildings and runways. Short term contractual commitments such as labor requirements, wages and salaries, and maintenance, are defined as variable costs. Variable costs include all costs other than fixed costs. It is assumed that vehicles can be bought and sold relatively easily, and therefore their costs are included as variable costs.

Direct and Indirect Cost; In the airline industry costs are typically divided among direct and indirect operating expenses. Direct cost are those costs directly related to operating the aircraft. These include the cost of the aircraft, hull insurance, flight crew, fuel and oil, direct maintenance, and maintenance burden. Indirect cost usually include those costs described above as fixed cost. These include items such as terminal investments, runway investments, and the maintenance of these facilities. Basically all cost associated with services performed on the ground are included in this category.

Capital Recovery Factor: The capital recovery factor estimates the annual or periodic equivalent of a monetary investment. The annual percentage of the investment that is to be assigned to each asset deter-



mined by its expected life (n), scrap value (s), and the rate of return (r). In this analysis the scrap value for equipment and structures is assumed to be zero so the formula for calculating the capital recovery factor is simplified to the following equation:

$$\text{Capital Recovery Factor (CRF)} = \frac{r(1+r)^n}{(1+r)^n - 1}$$

Fleet Requirements: For the purpose of this analysis it is assumed that vehicles may be bought or sold at will, so vehicle costs are considered part of variable costs. The system operator is required to have the correct number of vehicles to satisfy demand. A 10% addition was made to the fleet to represent the maintenance reserve.

Vehicle requirements for each of the technologies considered were computed from formulas derived by Morlok. Morlok described two cases or situations for calculating vehicle requirements: (Morlok, 1967, pp. 79-80).

Case I :  $TT / 2 \leq PH$

Number of vehicles required for bi-directional service equals:

$$2 [(((TT) \cdot (OHD/PHD)) / (2 \cdot OHD)) + 1]$$

Case II :  $TT / 2 \geq PH$

This describes the more complicated circumstances where vehicle departures are more frequent during the peak period. The number of vehicles required for bi-directional service equals:

$$2[PH((OHD/PHD-1)/OHD)+(TT/2 \cdot OHD)+1]$$

where

TT = round trip time of service (including both turn-around times)

PH = peak period of service in hours

OHD = base period headway

PHD = peak period headway

[ ] = the largest integer contained within brackets

## 2. THE VTOL COST MODEL

The VTOL cost model develops short haul system costs for a 45 passenger tilt-rotor aircraft. Costs are separated into two categories - direct operating cost and indirect operating cost. Direct operating cost encompass the following categories: fleet investment, hull insurance, flight crew, fuel and oil, direct maintenance, and maintenance burden. Indirect operating costs include: terminal construction, flight deck investment, terminal charges, aircraft parking, aircraft maintenance and engine overhaul base, central office building, terminal staff, and miscellaneous costs.

### 2.1. DIRECT OPERATING COST

#### Annual Cost of Fleet Investment

The annual cost of fleet investment equals the capital recovery factor times the total airplane investment. The capital recovery factor (CRF) equals .18448, where the capital recovery factor is a function of scrap value, rate of return, and expected life. Scrap value is expected to be zero (Roberts, 1969, p. 9, as referenced in Bolusky et al, 1972) after twelve years of normal airplane life (Hill, et al., 1971, p. 115, as referenced in Bolusky et al., 1972). Total airplane investment equals the cost of vehicle equipment (air frame, engines, avionics, and spare parts) multiplied by the number of vehicles in the system.

The airplane investment was estimated at \$9 million based on the 1974 approximation in Magee et al.(1975) at approximately \$5 million for the baseline VTOL tilt-rotor with a \$90/lb airframe cost. The 1974 estimate was updated to 1982 dollars by multiplying it by the appropriate

consumer price index. The resulting \$9 million price tag was not considered out of line for a new aircraft of this size and technology.<sup>1</sup> Annual cost of fleet investment was calculated as follows:

$$\text{ACTI} = 0.18448 \times \$9 \text{ million} \times \text{BNTR}$$

#### Hull Insurance

The annual cost of hull insurance is computed by multiplying the hull insurance rate by the aircraft flyaway cost less spare parts and by the number of aircraft in the system. The hull insurance rate used was 2% (Roberts, 1969 A, p. 13, as referenced in Bolusky et al, 1972).

Volume II of the 1972 DOT report gave flyaway cost for several aircraft. Based on this data an average value for flyaway cost less spare parts was estimated to be about 86% of the total investment cost for an aircraft. Therefore, the flyaway cost less spare parts was approximated to be about \$7.74 million. The annual hull insurance cost was calculated as follows:

$$\text{HI} = 0.02 \times \$7.74 \text{ million} \times \text{BNTR}$$

#### Flight Crew

Annual crew cost is tabulated as the total number of flight hours times the cost of crew per flight hour. The crew consists of a pilot and co-pilot. An estimate for crew cost was given as \$80 per flight hour for a DHC-7 aircraft (DASH 7) in the 1972 DOT report. Since that aircraft is similar in size to the VTOL aircraft in this analysis, and since both aircraft require specialized pilot skills (i.e. one aircraft has STOL capability and the other one VTOL capability), it was assumed that their crew costs would be similar. The DHC-7 crew cost was updated to 1982 dollars by multiplying it by the appropriate cost recovery index

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<sup>1</sup>This statement is based on a conversation on January 17, 1985 with Ransome Airlines who quoted the price of this aircraft as \$7.5 million (the DASH-7 is similar to tilt-rotor aircraft in size and design).

for labor. The annual crew cost (FC) was estimated as:

$$FC = \$240 \times AFH$$

### Fuel

The annual cost of fuel was determined for the tilt-rotor aircraft on a stage length basis. Annual cost of fuel was computed by multiplying the fuel consumption for each flight by the annual number of one way flights. Fuel consumption estimation for each flight was based on the mission profile tabulation for the aircraft, as presented in NASA Report CR-2544. Using the information from the mission segment analysis (Magee et al, 1975, p. 36) regarding cruise distances, a linear approximation for fuel was graphed as shown in Figure 1. An equation was formulated for the fuel consumption in pounds which was converted to fuel consumption in gallons. The fuel cost per flight was calculated by multiplying the number of gallons used by the cost per gallon of fuel. This cost was estimated at \$0.95 per gallon (Air Transport World, July 1982). Annual cost for fuel was calculated as follows:

$$FO = \frac{(277 + 8.63 \times SL)}{6.5} \times (\$0.95/\text{gallon}) \times DFREQ \times 365$$

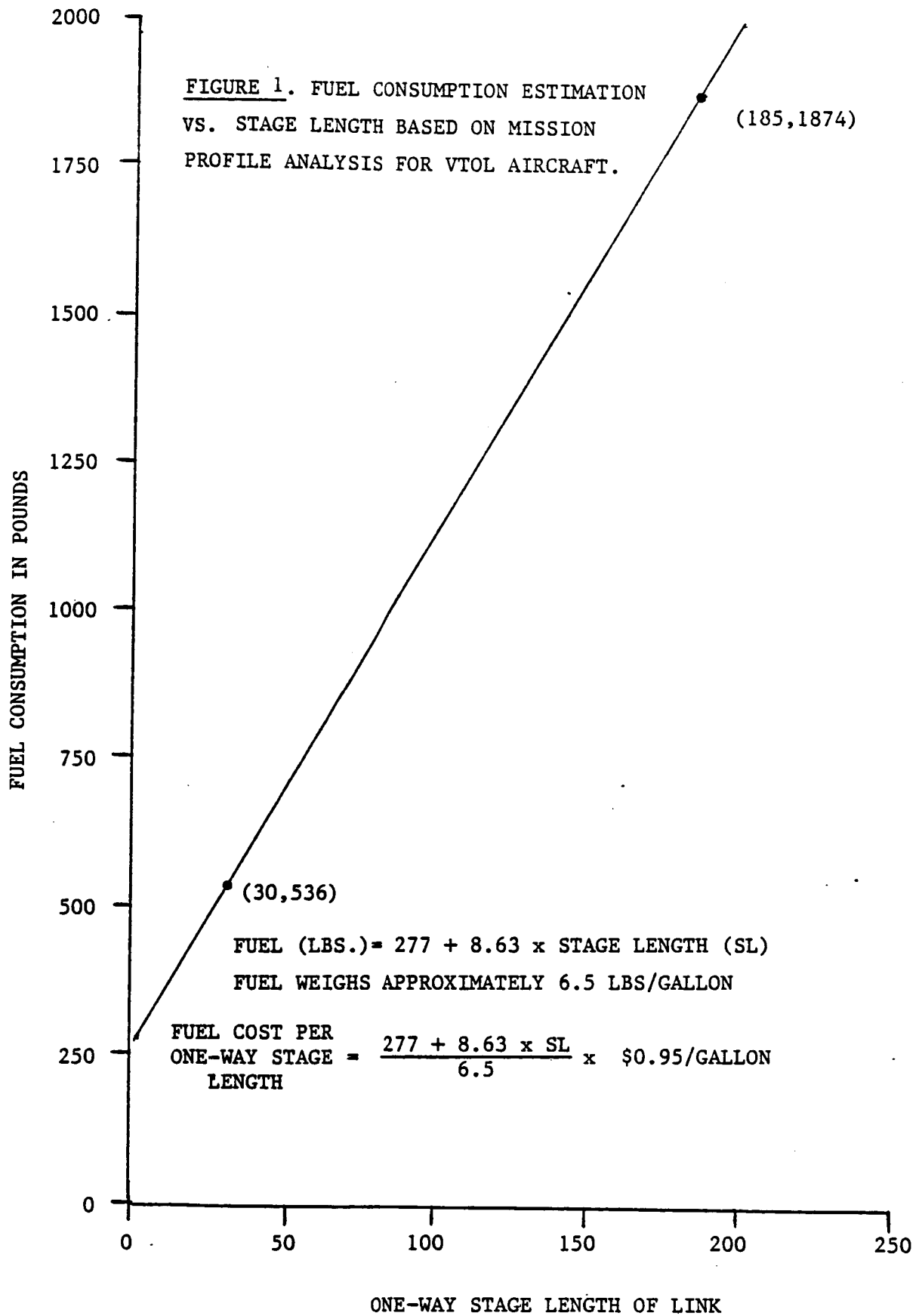
### Direct Maintenance

The annual cost of direct maintenance consists of labor and materials. Table XXI in NASA Report CR-2544, estimated direct maintenance in 1974 dollars per seat mile as \$0.0051. Labor cost was increased by a factor of 3 and materials by a factor of 1.8 to take into account 1982 price changes. The resulting direct maintenance cost was \$0.0158 per seat mile. The annual direct maintenance cost was calculated as follows:

$$DM = \$0.0158 \times 45 \text{ seats/aircraft} \times \text{stage length} \times \# \text{ of flights}$$

### Maintenance Burden

Maintenance burden is calculated as a percentage of the total annual cost of direct maintenance for labor and materials. Maintenance burden equals 60% of direct maintenance cost (Roberts, 1971, as referenced in



1972 DOT report). Annual cost of aircraft maintenance burden is calculated as follows:

$$AMB = 0.60 \times DM$$

## 2.2. INDIRECT OPERATING COST

It will be assumed that at each node a small terminal must be constructed to handle the new VTOL traffic to this airport. This construction will include a flight deck, gate areas, and passenger handling areas. The land required for this facility will be relatively small and it will be assumed that it is already the property of the airport so no fees will be charged. All of the relationships for indirect operating cost came from the 1972 DOT report, and all of the cost were updated using appropriate indexes to 1982 dollar amounts.

### Flight Deck

The annual cost of the flight deck equals the capital recovery factor for structures (35 year expected life and zero salvage value), multiplied by the flight deck investment. An annual maintenance charge is added to this computation.

$$FDI = 0.15113 \times 80,000 \text{ ft}^2 \times \$30/\text{ft}^2 \times 112,500 \text{ ft}^2 \times \$15/\text{ft}^2$$

$$FDI = \$617.764$$

$$\text{where: runway dimensions} = 200 \text{ feet by } 400 \text{ feet} = 80,000 \text{ ft}^2$$

$$\text{taxiway area} = 750 \text{ feet by } 150 \text{ feet} = 112,500 \text{ ft}^2$$

$$\text{runway construction cost} = \$30 \text{ per square foot}$$

$$\text{taxiway construction} = \$15 \text{ per square foot}$$

$$CRF = 0.15113$$

$$FDM = 192,500 \text{ ft}^2 \times \$0.033/\text{ft}^2 = \$6,334$$

$$\text{where: maintenance cost} = \$0.033 \text{ per square foot}$$

$$\text{pavement area} = 80,000 \text{ ft}^2 + 112,500 \text{ ft}^2 = 192,500 \text{ ft}^2$$

### Gate Area

The annual cost of the gate area includes the construction cost plus an annual gate area maintenance cost.

$$GA = CRF \times \text{ft}^2/\text{gate} \times \text{construction cost/gate} \times \text{number of gates}$$

$$GA = 0.15113 \times 15,105 \times \$15 \times 2$$

$$GA = \$68,484$$

$$\text{where: CRF} = 0.15113$$

$$\text{ft}^2/\text{gate} = 2.5 + (.6 (\text{AL}) + 25) \times 1.172(.6 (\text{AL}) + 25)$$

$$\text{ft}^2/\text{gate} = 15,105$$

$$\text{AL} = \text{aircraft length} = 78 \text{ feet}$$

$$\text{construction cost per square foot} = \$15$$

$$\text{number of gates is assumed to be } 2$$

$$GAM = 2 \times 15,105 \text{ ft}^2/\text{gate} \times \$0.033/\text{ft}^2$$

$$\text{where: square feet of gate area} = 2 \times 15,105$$

$$\text{maintenance cost per square foot} = \$0.033/\text{ft}^2$$

### Passenger Handling Area

The annual cost of the passenger handling area consists of the construction cost multiplied by the capital recovery factor and an annual maintenance cost.

$$PHA = CRF \times \text{sq.ft. of pass. handling area} \times \text{construction cost}/\text{ft}^2$$

$$\text{where: CRF} = 0.15113$$

$$\text{construction cost per square foot} = \$82$$

$$\text{square feet per terminal} = 7686 + 80.089 \times \# \text{ peak hour pass.}$$

$$\text{number of peak hour passengers} = \text{daily passenger flow} \times 0.1$$

$$PHAM = \text{maint. cost}/\text{ft}^2 \times \text{ft}^2 \text{ of passenger handling area.}$$

$$\text{where: maintenance cost per square foot} = \$6.46.$$

### Terminal Staff

The annual cost of terminal staff for the system is computed by multiplying the payroll cost for one terminal and the number of terminals in the system. These costs include administrative personnel, custodians, uniformed guards, clerks, ticket agents, electricians, fire and rescue personnel, and airfield personnel. The annual payroll for terminal staff was estimated to be about \$470,800.

### Passenger Terminal Charge

A terminal charge was calculated to cover those expenses incurred on the ground before the aircraft becomes airborne. Included in this cost was the additional cost due to a more complex air traffic control costs. The terminal charge for each passenger was estimated to be about \$10.

### Aircraft Parking

The system operator must provide parking for each and every aircraft in the system. This involves an investment in aircraft parking and an annual charge to maintenance. The size of the parking space for a tilt-rotor 45 passenger aircraft is assumed to be similar to the parking spaces required for a DHC-7 STOL aircraft which is similar in size to the tilt-rotor aircraft.

$$APRK = 0.15113 \times 10,368 \text{ ft}^2/\text{space} \times \$1.26/\text{ft}^2 \times \# \text{ of aircraft}$$

$$\text{where: CRF} = 0.15113$$

$$\text{parking space size} = 10,368 \text{ ft}^2$$

$$\text{construction cost per square foot} = \$1.26$$

$$APRKM = 10,368 \text{ ft}^2/\text{square} \times \$0.028/\text{ft}^2 \times \text{fleet size}$$

$$APRKM = \$290 \times \text{number of aircraft in system}$$

$$\text{where: parking space size} = 10,368 \text{ ft}^2$$

$$\text{maintenance cost per square foot} = \$0.028$$



### Aircraft Maintenance and Engine Overhaul Building

Assuming that the VTOL operation has been an added service by an existing commercial airline, the airline probably has sufficient facilities to handle the additional maintenance of the tilt-rotor aircraft. If no more than 10% of the aircraft are in for maintenance at on time, this will mean that additional space is required for only one or two aircraft, since for our analyses the fleet size is always less than 20. If the VTOL operation was independent, and only a small space was required for maintenance, renting space could be a possibility. No costs were added to the analysis for a maintenance and engine overhaul building.

### Central Office Building

The annual cost of the central office building is partitioned into three divisions: 1) annual cost of constructing the building, 2) annual cost of building maintenance, 3) average yearly salary of office building personnel.

As assumed previously, the VTOL service may become part of another existing airline already in operation, so no cost will be added for items 1 and 2 above. However, additional office personnel will be required to handle the additional passengers. This model estimated this number to be 0.01 multiplied by the number of daily passengers. Salaries for each of these employees was estimated at \$25,000/year. It was assumed that no additional space was required for these additional employees.

$$\text{PERC} = \$25,000/\text{year} \times 0.01 \times \text{CAP}$$

### Miscellaneous Cost

The miscellaneous cost category is made up of food, stewardess cost, advertising and publicity cost, passenger liability insurance, and other cost. Again, it was assumed that these costs would approximate those of the similar sized DHC-7 STOL aircraft.

$$\text{CMISC} = 0.3178 \times \text{total annual aircraft miles}$$

### 2.3. TOTAL COST EQUATIONS

The purpose of this section is to present the components which comprise each of the VTOL total cost equations and the cost per passenger mile equation corresponding to each one. Additionally, in Table 1, updated cost parameters used in the model are summarized by identifying the source and value of the original unit cost, and then stating the factor and source used to update this parameter to its present value.

#### 1. Average Annual Total Cost (TAAC):

##### Direct Operating Cost:

- Fleet Investment (ACTI) =  $0.18448 \times \$9 \text{ million} \times \text{BNTR}$
- Hull Investment (HI) =  $0.02 \times \$7.74 \text{ million} \times \text{BNTR}$
- Flight Crew (FC) =  $\$240 \times \text{AFH}$
- Fuel (FO) =  $\frac{277 + 8.63 \times \text{SL}}{6.5} \times \$0.95 \times \text{DFREQ} \times 365$
- Direct Maintenance (DM) =  $\$0.0158 \times 45 \times \text{SL} \times \text{annual \# flights}$
- Maintenance Burden (AMB) =  $0.60 \times \text{DM}$

##### Indirect Operating Cost:

##### -Terminal Cost (for each terminal):

1. Flight Deck Investment (FDI) = \$617,764

Flight Deck Maintenance (FDM) = \$6,334

2. Gate Area Investment (GA) = \$68,484

Gate Area Maintenance (GAM) = \$997

3. Passenger Handling Area Investment (PHA):

$0.15113 \times (7686 + 80.089 (\text{CAP} \times 0.1)) \times \$89$

Passenger Handling Area Maintenance (PHAM):

$(7686 + 80.089(\text{CAP} \times 0.1)) \times \$6.46$

4. Terminal Staff (TSTAF) = \$470,800

-Passenger Terminal Charge (TERPAX) =  $\text{BNTP} \times \$10$

-Aircraft Parking (APRK) =  $\$1974 \times \text{BNTR}$

-Aircraft Parking Maintenance (APRKM) =  $\$290 \times \text{BNTR}$

-Central Office Building (PERC) =  $\$25,000 \times 0.01 \times \text{CAP}$

-Miscellaneous Cost (CMISC) =  $\$0.3178 \times \text{TAM}$

$\text{TAAC} = \text{ACTI} + \text{HI} + \text{FC} + \text{FO} + \text{DM} + \text{AMB} + (\text{no. of terminals}) \times (\text{FDI} + \text{FDM} + \text{GA} + \text{GAM} + \text{PHA} + \text{PHAM} + \text{TSTAF}) + \text{TERPAX} + \text{APRK} + \text{APRKM} + \text{PERC} + \text{CMISC}$

The cost per passenger mile based on total cost is calculated by taking the above cost (TAAC) and dividing it by the annual number of passengers on the system multiplied by the one-way stage length.

$$PPCUU = \frac{TAAC}{SL \times BNSP}$$

## 2. Average Annual Total Cost Excluding Fixed Facility Capital Cost (TALC):

This cost is equal to the total cost less capital expenditures for flight deck investments, gate area investments, passenger handling area investments, and aircraft parking investment. The cost equation is as follows:

$$TALC = ACTI + HI + FC + FO + DM + AMB + (\text{no. of terminals}) \times (FDM + GAM + PHAM + TSTAF) + TERPAX + ARPKM + PERC + CMISC$$

The cost per passenger mile based on total cost excluding fixed facility capital cost is calculated by taking the above cost (TALC) and dividing it by the annual number of passengers on the system multiplied by the one-way stage length.

$$PPUUV = \frac{TALC}{SL \times BNSP}$$

## 3. Average Annual Total Cost Excluding All Capital Cost (TALCAV):

This cost is equal to the total cost excluding fixed facility cost calculated above, minus the annual fleet investment.

$$TALCAV = TALC - ACTI$$

The cost per passenger mile based on total cost excluding all capital cost is calculated as follows:

$$PPWOV = \frac{TALCAV}{SL \times BNSP}$$

TABLE 1. Summary of Updated Cost Parameters:

Cost Component	Parameter Value (Year)	Source of Original Parameter	Updating Factor	Source of Updating Factor	Parameter Value (1982)
Aircraft cost	\$5 million (1974)	NASA Report CR-2545	1.8	p. 739 U.S. Statistical Abstract, 1984	\$9 million
Flight crew	\$80 (1971)	1972 DOT Report	3.0	p. 59 AAR Yearbook	\$240
Direct Maintenance	.0051 (1974)	NASA Report CR-2545	3.0 (labor) 1.8 (materials)	p. 59 AAR Yearbook p. 739 U.S. Statistical Abstract, 1984	.0158
Flight deck: -runway construction	\$12 (1970)	1972 DOT Report	2.5	p. 739 U.S. Statistical Abstract, 1984	\$30
-taxiway construction	\$6 (1970)		2.5		\$15
-maintenance cost	\$0.013 (1970)		2.5		\$0.033
Gate Area: -construction cost	\$12 (1970)	"	2.5	"	\$15
-maintenance cost	\$0.013 (1970)		2.5		\$0.033
Passenger Handling Area: -construction cost	\$30 (1970)	"	2.73	"	\$82
-maintenance cost	\$2.34 (1971)		2.76		\$6.46
Aircraft Parking: -construction	\$0.50 (1970)	"	2.5	"	\$1.26
-maintenance cost	\$0.011 (1970)		2.5		\$0.028
Miscellaneous cost	.1589 (1972)	1972 DOT Report	2	p. 739, U.S. Statistical Abstract, 1984	0.3178

#### 2.4. COST PER PASSENGER MILE

The purpose of this section is to present the cost per passenger mile and output capabilities for the 45 passenger tilt-rotor aircraft. Three different values were calculated for cost per passenger mile. These were based on the following:

- 1) Total cost (see Figure 2)
- 2) Total cost minus fixed facility capital cost (see Figure 3)
- 3) Total cost minus all capital cost (See Figure 4)

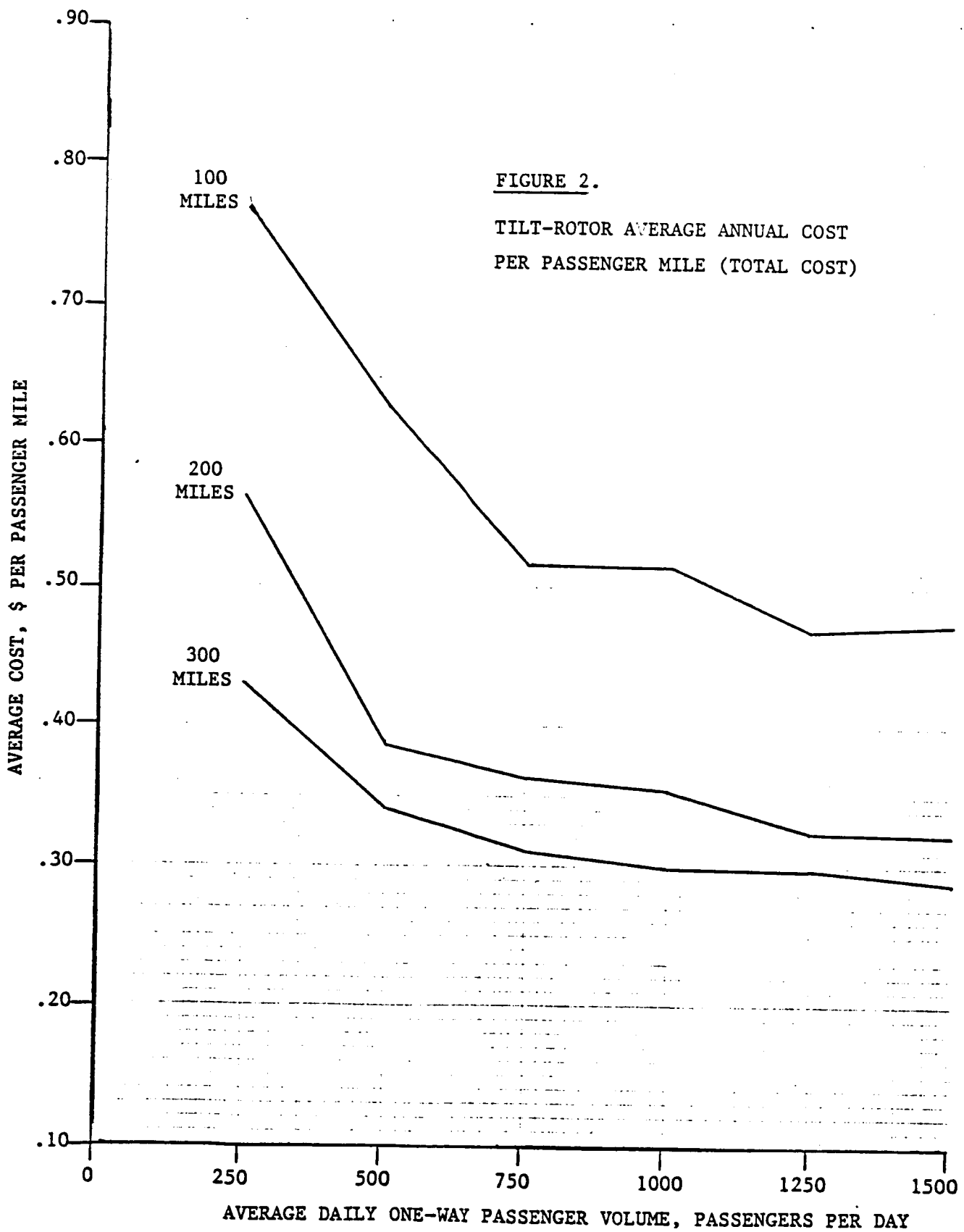
The costs per passenger mile for each of these calculations are summarized in Table 2. Figure 2 shows a graph of average cost per passenger mile based on total cost, versus average one-way daily passenger volumes. For all stage lengths, cost per passenger mile decreased substantially over the 250-500 passenger range. Also, there is a significant reduction in costs as the stage lengths increase. Beyond the 500 passenger per day level, costs per passenger mile remain relatively constant. This is partially due to the higher load factors observed over this range than those experienced at the 0-500 passenger range (in this range the minimum frequency constraint governed the number of operations resulting in lower load factors). Most importantly though, the sunk costs resulting from terminal, runway, and aircraft investments are less per passenger-mile when more passengers are carried and longer stage lengths are traveled (see Table 3).

Figure 3 shows a graph of average cost per passenger mile based on total cost excluding fixed facility capital cost, versus average one-way daily passenger volumes. Perhaps this is the most appropriate cost per passenger mile considered since many of the costs associated with capital investments in terminals and flight decks may be financed by federal, state, and local governments, rather than charged directly to an airline operation. Costs are slightly lower than those observed in Figure 2 and generally follow the pattern that these costs do.

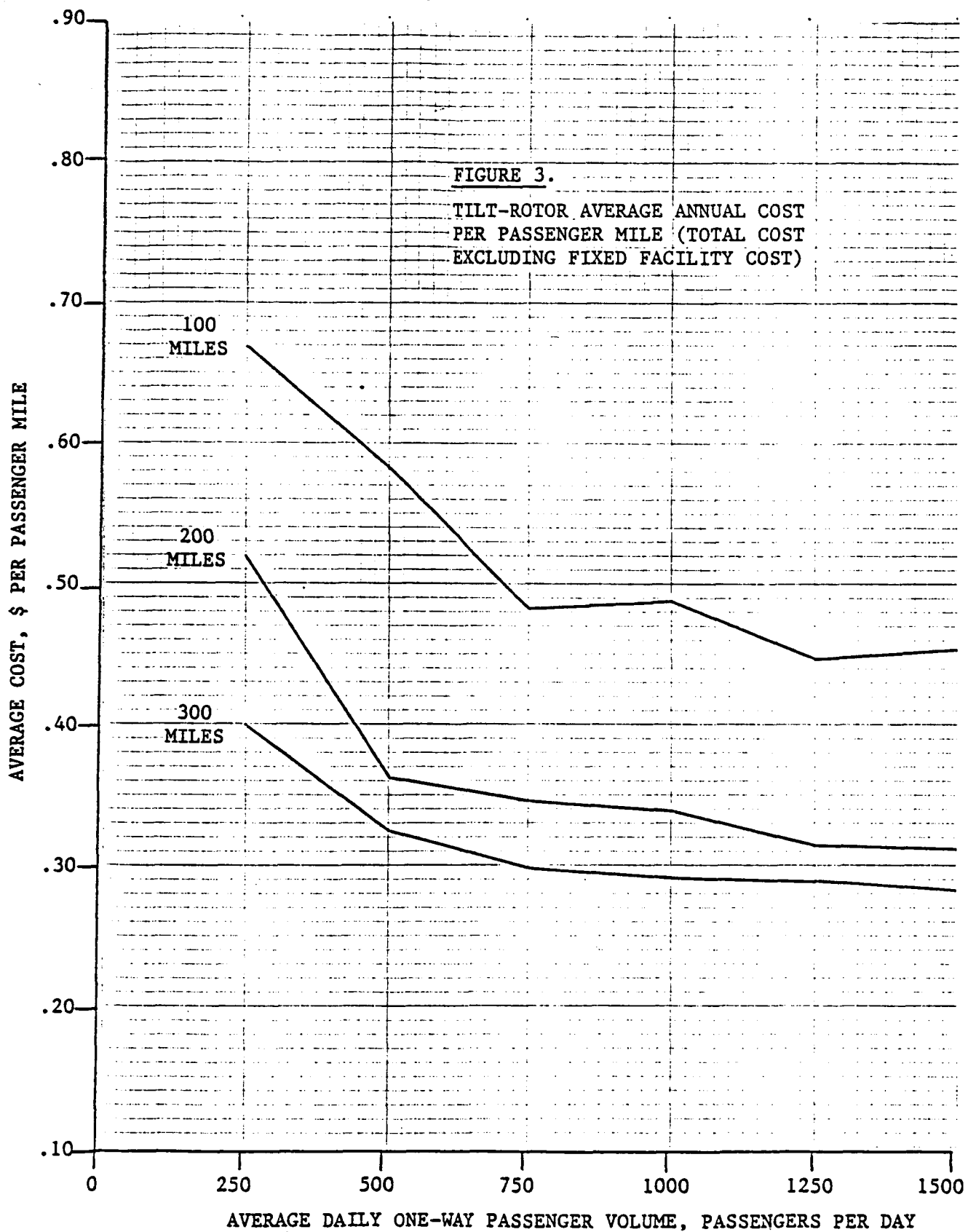
Figure 4 shows a graph of average cost per passenger mile based on total cost excluding all capital cost, versus average one-way daily passenger volumes. Costs are much lower than those observed in both Figures 2 and 3, which reflects the significance of aircraft cost on overall cost. The cost per passenger mile decreases slightly over the 250-500 passenger range, and remains relatively constant for passenger volumes greater than this.

TABLE 2. Tilt-rotor costs per passenger-mile vs. stage length and passenger volume.

<u>Stage Length, mi.</u>		Average Cost, \$/pass. mile	
Directional Pass. Volume, pass./day	Total Cost	Total Cost minus Fixed Facility Cost	Total Cost minus All Capital Cost
<u>100 miles</u>			
250	.7705	.6791	.4062
500	.6296	.5811	.3537
750	.5163	.4821	.3305
1000	.5142	.4872	.3280
1250	.4693	.4466	.3192
1500	.4725	.4526	.3162
<u>200 miles</u>			
250	.5649	.5191	.2917
500	.3876	.3633	.2496
750	.3617	.3446	.2384
1000	.3530	.3394	.2371
1250	.3244	.3131	.2312
1500	.3220	.3121	.2287
<u>300 miles</u>			
250	.4300	.3995	.2478
500	.3401	.3239	.2178
750	.3102	.2987	.2078
1000	.2992	.2902	.2068
1250	.2961	.2885	.2035
1500	.2884	.2818	.2009







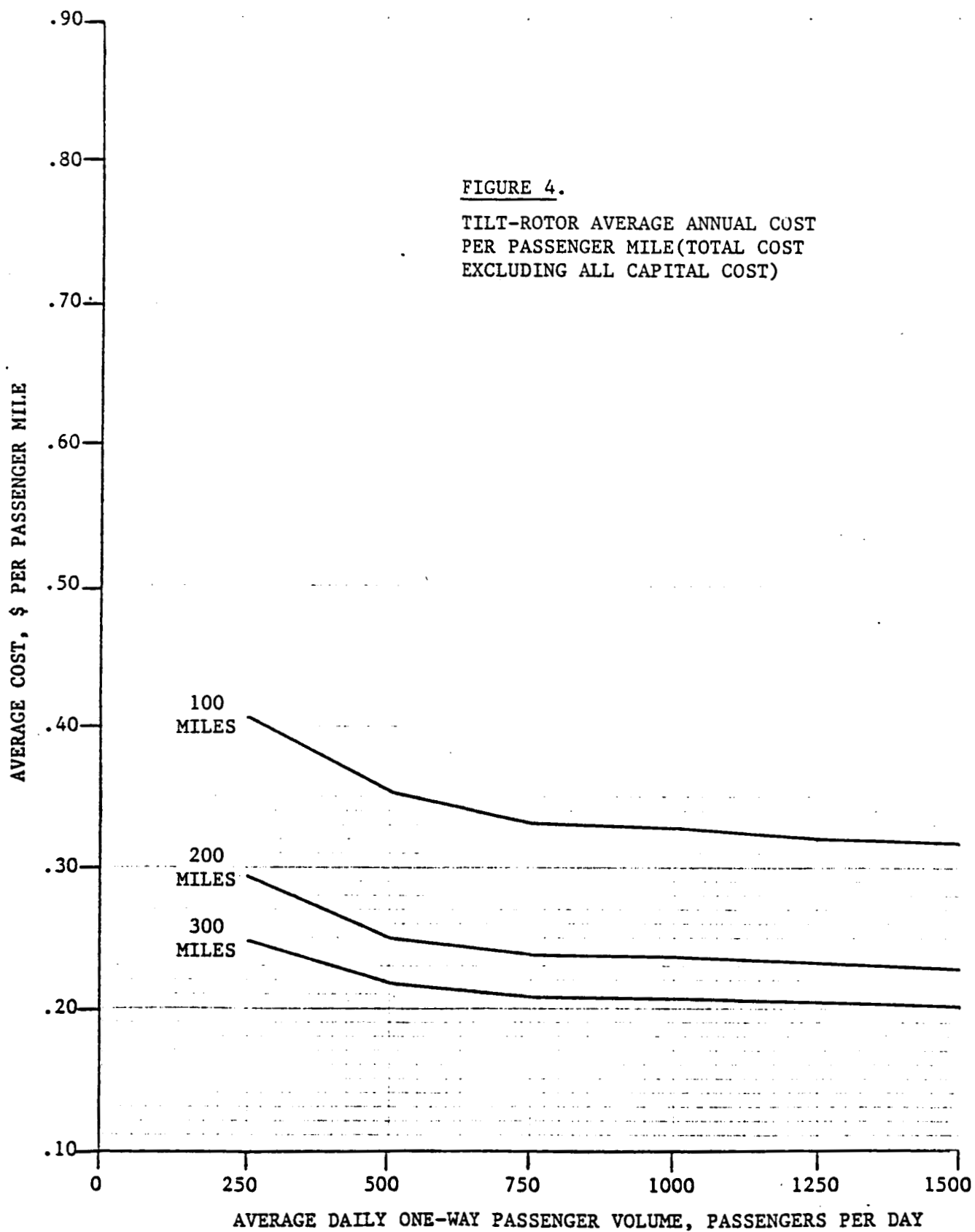


TABLE 3. Tilt-rotor system costs and characteristics vs. stage length and passenger volume.

Stage Length, mi	Fleet Directional				
Directional Pass. Size, Headways, Hrs./Dep.				Terminal Cost	Total Cost,
Vol., pass./day Veh. Peak Base				Per Pass., \$/Pass.	\$1000/yr.
<u>100 miles</u>					
250	3	1.00	1.71	25.18	14,062
500	5	0.67	0.86	18.00	22,981
750	5	0.44	0.60	15.61	28,265
1000	7	0.33	0.44	14.41	37,538
1250	7	0.29	0.35	13.70	42,822
1500	9	0.24	0.30	13.22	51,741
<u>200 miles</u>					
250	5	1.00	1.71	25.18	20,620
500	5	0.67	0.86	18.00	28,295
750	7	0.44	0.60	15.61	39,606
1000	9	0.33	0.44	14.41	51,535
1250	9	0.29	0.35	13.70	59,211
1500	11	0.24	0.30	13.22	70,521
<u>300 miles</u>					
250	5	1.00	1.71	25.18	23,543
500	7	0.67	0.86	18.00	37,244
750	9	0.44	0.60	15.61	50,945
1000	11	0.33	0.44	14.41	65,532
1250	14	0.29	0.35	13.70	81,051
1500	16	0.24	0.30	13.22	94,753

## 2.5. SENSITIVITY ANALYSIS

Since the VTOL aircraft under consideration is based on a future technological innovation and lacks an established cost background, a sensitivity analysis was performed. Several parameter values were changed in the model developed for the tilt-rotor aircraft investigated to determine if those changes would have a significant effect on passenger mile cost. The sensitivity analysis examined aircraft cost, aircraft speed, crew cost, direct maintenance cost, fuel cost, interest rates, load factors, terminal cost, and aircraft turn-around times. Table 4 presents a summary of these sensitivity analyses. Each column presents the effect of a change in the cost parameter in the direction and amount shown, e.g., column 1 refers to a 20% reduction in vehicle costs. The entries in the column are the percentage changes in a particular overall cost measure for a given passenger volume, e.g., the first row gives the percent change in total cost per passenger mile. Thus a 20% drop in aircraft cost reduces total cost per passenger mile at a 100 passenger per day volume by 7.74%.

Aircraft Cost: Changes in aircraft cost are particularly sensitive for the tilt-rotor technology. As would be expected, the effect on passenger mile cost is more significant at shorter stage lengths and smaller passenger volumes. Even when all capital cost are excluded in calculating passenger mile cost, changes in aircraft cost have a slight influence since hull insurance cost is a function of aircraft cost.

Vehicle Speed: The effect of varying aircraft speed was insignificant at some stage lengths and passenger demands, but very significant at others. The reason for significant changes is that vehicle speed had an effect on fleet size. Aircraft speed also influences the number of annual flight hours which was a factor in calculating certain costs.

Crew Cost: Crew cost changed passenger cost very little and was judged to be a non-sensitive parameter.

Direct Maintenance: The effect of changing direct maintenance cost was also judged to be non-sensitive.

Fuel Cost: Changes in fuel expenditures had little influence on passenger mile cost. The minor effect it had was more apparent at longer stage lengths and higher passenger demand levels.

TABLE 4. SENSITIVITY ANALYSIS FOR VTOL (TILT-ROTOR)  
% CHANGE IN COST PER PASSENGER MILE

COST		VEH. COST (-20%)	VEH. SPEED (-20%)	CREW COST (+10%)	DIR. MAINT. (-20%)	FUEL COST (-20%)	INT. RATE (-20%)	LOAD FACTOR (-10%)	TERM. COST (+100%)	T. A. TIME (+25%)
1	STAGE LENGTH	AVG. DAILY PASSENGERS								
	100	500	-7.74	+1.32	+0.99	-1.30	-1.89	-6.68	+2.52	+32.68
		3000	-6.31	+1.86	+1.40	-1.82	-2.67	-4.40	+4.78	+27.98
	200	500	-8.80	+1.81	+1.03	-1.77	-2.28	-6.57	+3.01	+22.29
		3000	-5.65	+10.47	+1.55	-2.67	-3.45	-3.82	+13.88	+20.53
	300	500	-7.72	+2.37	+1.21	-2.33	-2.86	-5.77	+3.77	+19.51
2		3000	-6.10	+5.34	+1.60	-2.98	-3.68	-3.92	+10.40	+15.29
	100	500	-8.78	+1.50	+1.12	-1.47	-2.15	-5.02	+2.86	+23.66
		3000	-6.58	+1.94	+1.46	-1.90	-2.78	-3.76	+5.02	+24.86
	200	500	-9.57	+1.96	+1.12	-1.93	-2.49	-5.47	+3.27	+15.49
		3000	-5.86	+10.77	+1.60	-2.79	-3.59	-3.36	+14.29	+18.01
	300	500	-8.31	+2.53	+1.30	-2.53	-3.08	-4.76	+4.03	+13.39
3		3000	-6.28	+7.03	+1.60	-3.09	-3.76	-3.58	+10.61	+13.31
	100	500	-1.26	+2.51	+1.87	-2.46	-3.62	0.00	+4.78	+39.56
		3000	-0.82	+2.78	+2.06	-2.75	-4.02	0.00	+7.15	+35.58
	200	500	-1.47	+3.46	+1.99	-3.43	-4.42	0.00	+5.79	+27.53
		3000	-0.70	+4.77	+2.19	-3.80	-4.90	0.00	+9.58	+24.57
	300	500	-1.13	+4.12	+2.14	-4.04	-4.96	0.00	+6.54	+21.63
		3000	-0.75	+4.83	+2.24	-4.28	-5.28	0.00	+9.86	+18.67
	1. TOTAL COST									
	2. TOTAL COST EXCLUDING FACILITY CAPITAL COST									
	3. TOTAL COST EXCLUDING ALL CAPITAL COST									

Interest Rates: The interest was a significant factor at lower passenger demand volumes. This is not surprising since the VTOL operation cost were influenced by both expansive fleet investments and high facility capital expenditures.

Load Factors: Reducing the maximum allowable load factors had a significant influence on VTOL passenger mile cost, particularly at higher passenger volumes. This was the result of more frequent aircraft operations and larger fleet sizes.

Terminal Cost: A 100% change in terminal cost had little effect on VTOL passenger mile cost. The small influence that it had was more significant at shorter stage lengths.

Turn-around Time: Turn-around time was not a significant factor for most stage lengths or passenger volumes. This is similar to the effect which was observed for differences in aircraft speed where different turn-around times may influence fleet size requirements.

### 3. THE CTOL COST MODEL

The CTOL cost model develops short haul system costs for the McDonnell Douglas DC-9-30 aircraft. All seating is coach and the aircraft has a 115 passenger capacity. Costs are separated into two categories - direct operating cost and indirect operating cost. Direct operating cost includes the following categories: fleet investment, hull insurance, flight crew, fuel and oil, direct maintenance and maintenance burden. Indirect operating costs include: air passenger terminal charge, aircraft parking cost, central office building costs, and miscellaneous costs.

#### 3.1. DIRECT OPERATING COST

##### Annual Cost of Fleet Investment

The annual cost of fleet investment equals the capital recovery factor times the total airplane investment. The airplane investment was estimated at \$12,842,000 based on the 1972 estimate of \$5,500,000 for a new aircraft. The 1972 cost was updated to 1982 using the appropriate wholesale price index for capital equipment as referenced in the 1984 Statistical Abstract of the United States. Actually, the DC-9-30 aircraft was no longer coming off the assembly line in 1982 and used aircraft were available through the resale market at approximately \$7 million per aircraft<sup>2</sup>. The influence of aircraft cost on passenger mile cost is considered in the sensitivity analysis. Annual cost of fleet investment was calculated as follows:

$$ACTI = 0.18448 \times \$12,842,000 \times BNTR$$

where BNTR = number of CTOL (DC-9-30) aircraft in system  
CRF = 0.18448

#### Hull Insurance

The annual cost of hull insurance is computed by multiplying the previously used hull insurance rate of 2% by the aircraft flyaway cost less spare parts and by the number of aircraft in the system. Volume II of the 1972 DOT report indicated that the flyaway cost less spare parts was \$5 million for the DC-9-30 or approximately 90.909% of the flyaway cost. Therefore, the flyaway cost less spare parts for 1982 was estimated to equal this same percentage multiplied by the aircraft cost. The annual hull insurance cost was calculated as follows:

$$HI = 0.02 \times 0.90909 \times \$12,842,000 \times BNTR$$

where BNTR = number of CTOL (DC-9-30) aircraft in system

#### Flight Crew

Annual crew cost is tabulated as the total number of flight hours times the cost of crew per flight hour, where the crew consists of a pilot and a co-pilot. Crew cost for 1982 were taken from the 1983 report "Aircraft Operating Cost and Performance Report". From line 1, the crew cost per block hour was estimated at \$290.51. The annual crew cost (FC) was calculated as follows:

$$FC = \$290.51 \times AFH$$

#### Fuel and Oil

The annual cost of fuel and oil is determined for the DC-9-30 on a

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<sup>2</sup> The source of this statement was from a phone conversation in March 1985 with a marketing representative for the McDonnell Douglas Corporation.



flight hour basis. Fuel and oil cost for 1982 were taken from the 1983 report "Aircraft Operating Cost and Performance Report". From line 2, fuel and oil cost per block hour was estimated at \$799.35. Line 36 indicates that this estimate was based on the fuel price of \$0.95716 per gallon. Annual cost for fuel and oil was calculated as:

$$FO = \$799.35 \times AFH$$

#### Direct Maintenance

The annual cost of direct maintenance consists of labor and materials. Direct maintenance cost for 1982 were based on the 1983 report "Aircraft Operating Cost and Performance Report". From line 7, direct maintenance cost per block hour was estimated as \$124.21. The annual cost for direct maintenance was calculated as:

$$DM = \$124.21 \times AFH$$

#### Maintenance Burden

Similar to the VTOL cost model, annual cost of aircraft maintenance burden is equal to 60% of direct maintenance cost.

$$AMB = 0.60 \times DM$$

### 3.2. INDIRECT OPERATING COST

It will be assumed that all terminal structures have been previously constructed and paid for. Charges that will be applicable will be those resulting from maintaining the facilities and those resulting from greater personnel cost as a result of an increase of passengers using the system. All of the relationships for indirect operating cost came from the 1972 DOT report and all of the cost were updated using appropriate indexes to 1982 dollar amounts.

### Passenger Terminal Charge

A terminal charge was calculated to cover those expenses incurred on the ground before the aircraft becomes airborne. These expenses include such things as maintenance and operating costs of runways, taxiways, and gate areas. Volume II of the 1972 DOT report, estimated this terminal cost at \$12 per passenger. Using the appropriate consumer price index this cost was updated to approximately \$27.70 for 1982.

### Aircraft Parking

The system operator must provide parking for each and every aircraft in the system. This involves an investment in aircraft parking which is assumed to be completely paid for, and an annual charge for maintenance which is calculated as follows:

$$\text{APRKM} = \$0.028 \times 14,715 \text{ ft}^2 \times \text{BNTR}$$

$$\begin{aligned} \text{where: maintenance cost per square foot} &= \$0.028 \\ \text{parking area per aircraft} &= 14,715 \text{ ft}^2 \end{aligned}$$

### Central Office Building

The annual cost of the central office building is partitioned into three divisions: 1) annual cost of constructing the building; 2) annual cost of building maintenance; 3) average yearly salary of office building personnel.

Making the assumption that this service may become an addition to an existing airline operation it was assumed that no cost would be added for items 1 and 2 above. However, additional office personnel will be required to handle the additional passengers. This model estimated this number to be 0.01 multiplied by the number of daily passengers. Salaries for each of these employees was estimated at \$25,000/year. It was assumed that no additional space was required for these additional employees.

$$\text{PERC} = \$25,000/\text{year} \times 0.01 \times \text{CAP}$$

### Miscellaneous Cost

The miscellaneous cost category is made up of food, stewardess cost, advertising and publicity cost, passenger liability insurance, and other cost. The miscellaneous cost for the DC-9-30 aircraft was calculated as follows:

$$CMISC = 0.7616 \times TAM$$

### 3.2. TOTAL COST EQUATIONS

The purpose of this section is to present the components which comprise each of the CTOL total cost equations and the cost per passenger mile equation corresponding to each one. Additionally, in Table 5, updated cost parameters used in the model are summarized by identifying the source and value of the original factor, and then stating the factor and source used to update this parameter to its present value.

#### 1. Average Annual Total Cost (TAAC):

##### Direct Operating Cost:

- Fleet Investment, ACTI =  $0.18448 \times \$12,842,000 \times \text{BNTR}$
- Hull Insurance, HI =  $0.02 \times 0.90909 \times \$12,842,000 \times \text{BNTR}$
- Flight Crew, FC =  $\$290.51 \times \text{AFH}$
- Fuel and Oil, FO =  $\$799.35 \times \text{AFH}$
- Direct Maintenance, DM =  $\$124.21 \times \text{AFH}$
- Maintenance Burden, AMB =  $0.60 \times \text{DM}$

##### Indirect Operating Cost:

- Passenger Terminal Charge, TERPAX =  $\text{BNSP} \times \$27.70$
- Aircraft Parking Maintenance, APRKM =  $\$0.028 \times \$14,715 \text{ ft}^2 \times \text{BNTR}$
- Central Office Building, PERC =  $\$25,000 \times 0.01 \times \text{CAP}$
- Miscellaneous Cost, CMISC =  $0.7616 \times \text{TAM}$

$$\text{TAAC} = \text{ACTI} + \text{HI} + \text{FC} + \text{FO} + \text{DM} + \text{AMB} + \text{TERPAX} + \text{APRKM} + \text{PERC} + \text{CMISC}$$

The cost per passenger mile based on total cost (TAAC) is calculated as follows:

$$\text{PPCUU} = \frac{\text{TAAC}}{\text{SL} \times \text{BNSP}}$$

#### 2. Average Annual Total Cost Excluding All Capital Cost (TALCAV):

This cost is equal to the total cost calculated above, minus the annual fleet investment.

$$\text{TALCAV} = \text{TAAC} = \text{ACTI}$$

The cost per passenger mile based on total cost excluding all capital cost is calculated as follows:

$$\text{PPWOV} = \frac{\text{TALCAV}}{\text{SL} \times \text{BNSP}}$$

TABLE 5. Summary of Updated CTOL Cost Parameters.

Cost Component	Parameter Value (Year)	Source of Original Parameter	Updating Factor	Source of Updating Factor	Parameter Value (1982)
Aircraft cost	\$5,500,000 (1972)	1972 DOT Report	2.31	p. 487 U.S. Statistical Abstract, 1984	\$12,842,000
Passenger Terminal Charge	\$12 (1972)	1972 DOT Report	2.31	p. 487 U.S. Statistical Abstract, 1984	\$27.70
Aircraft Parking Maintenance Cost	\$0.011 (1970)	1972 DOT Report	2.5	p. 739 U.S. Statistical Abstract, 1984	\$0.028
Miscellaneous Cost	\$ .3808 (1972)	1972 DOT Report	2	p. 739 U.S. Statistical Abstract, 1984	\$0.7616

### 3.4. COST PER PASSENGER MILE

The purpose of this section is to present the cost per passenger mile and output capabilities for the 115 passenger DC-9-30 CTOL aircraft. Two different values were calculated for cost per passenger mile. These were based on the following:

- 1) Total cost (see Figure 5)
- 2) Total cost minus all capital cost (see Figure 6)

Since for this model, landing fees cover all airport charges, fixed facility costs alone cannot be separated out.

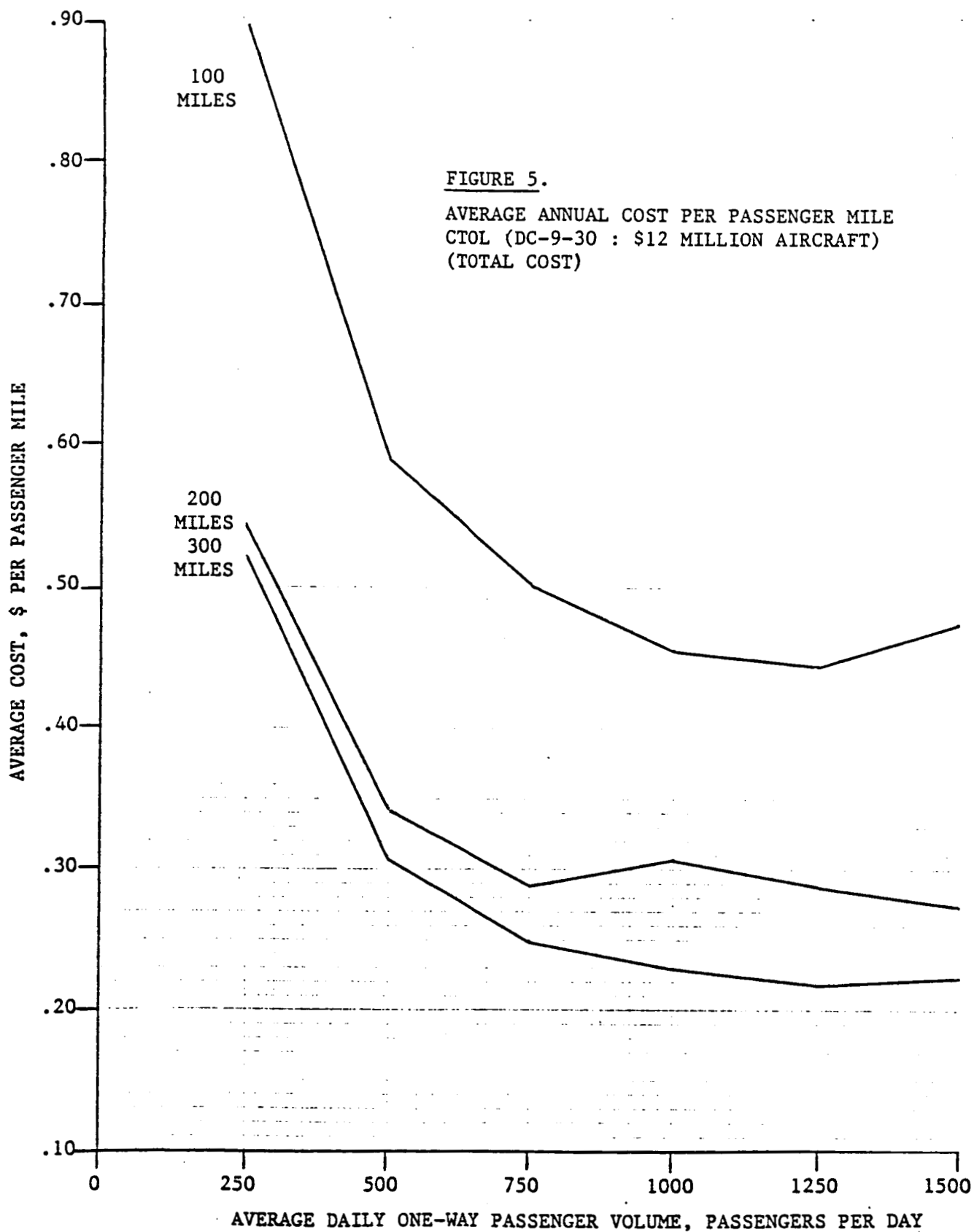
The costs per passenger mile for each of these calculations are summarized in Table 6. Figure 5 shows a graph of average cost per passenger mile based on total cost, versus average one-way daily passenger volumes. For all stage lengths, cost per passenger mile decreased substantially over the 250-500 passenger range. There is a significant reduction in costs as stage lengths increase from 100 miles to 200 miles. This reduction is minimal for the smaller passenger volumes as stage lengths increase from 200 miles to 300 miles, but more noticeable at larger passenger volumes. Beyond the 750 passenger level, costs per passenger mile remain relatively constant. This is due to the excess capacity observed at lower passenger volumes requiring aircraft investment costs to be distributed among fewer passengers. The excess capacity results because a certain number of flights are required to satisfy the minimum frequency constraints regardless of what the passenger demand is. This is evident in Table 7 which shows that the fleet size required at low passenger volumes (i.e. 500 daily passengers) is equivalent to the fleet size required at the 1500 or greater daily volumes.

Figure 6 shows a graph of average cost per passenger mile based on total cost excluding all capital cost, versus average one-way daily passenger volumes. At the lower passenger volumes, costs decrease substantially from those observed in Figure 5, which reflects the significance of aircraft cost at these demands. Cost per passenger mile decreases very little for passenger volumes greater than 500 passengers/day.

Table 6. CTOL costs per passenger mile vs. stage length and passenger volume.

<u>Stage Length</u> Directional Passenger Volume, pass./day	Average Cost, \$/pass. mile	
	Total Cost	Total Cost minus all Capital Cost
<u>100 miles</u>		
250	.9008	.5114
500	.5923	.3976
750	.5021	.3723
1000	.4664	.3691
1250	.4451	.3672
1500	.4752	.3670
<u>200 miles</u>		
250	.5449	.3502
500	.3434	.2461
750	.2889	.2240
1000	.3067	.2256
1250	.2889	.2240
1500	.2738	.2197
<u>300 miles</u>		
250	.5214	.3050
500	.3080	.1998
750	.2495	.1774
1000	.2297	.1756
1250	.2178	.1745
1500	.2226	.1721





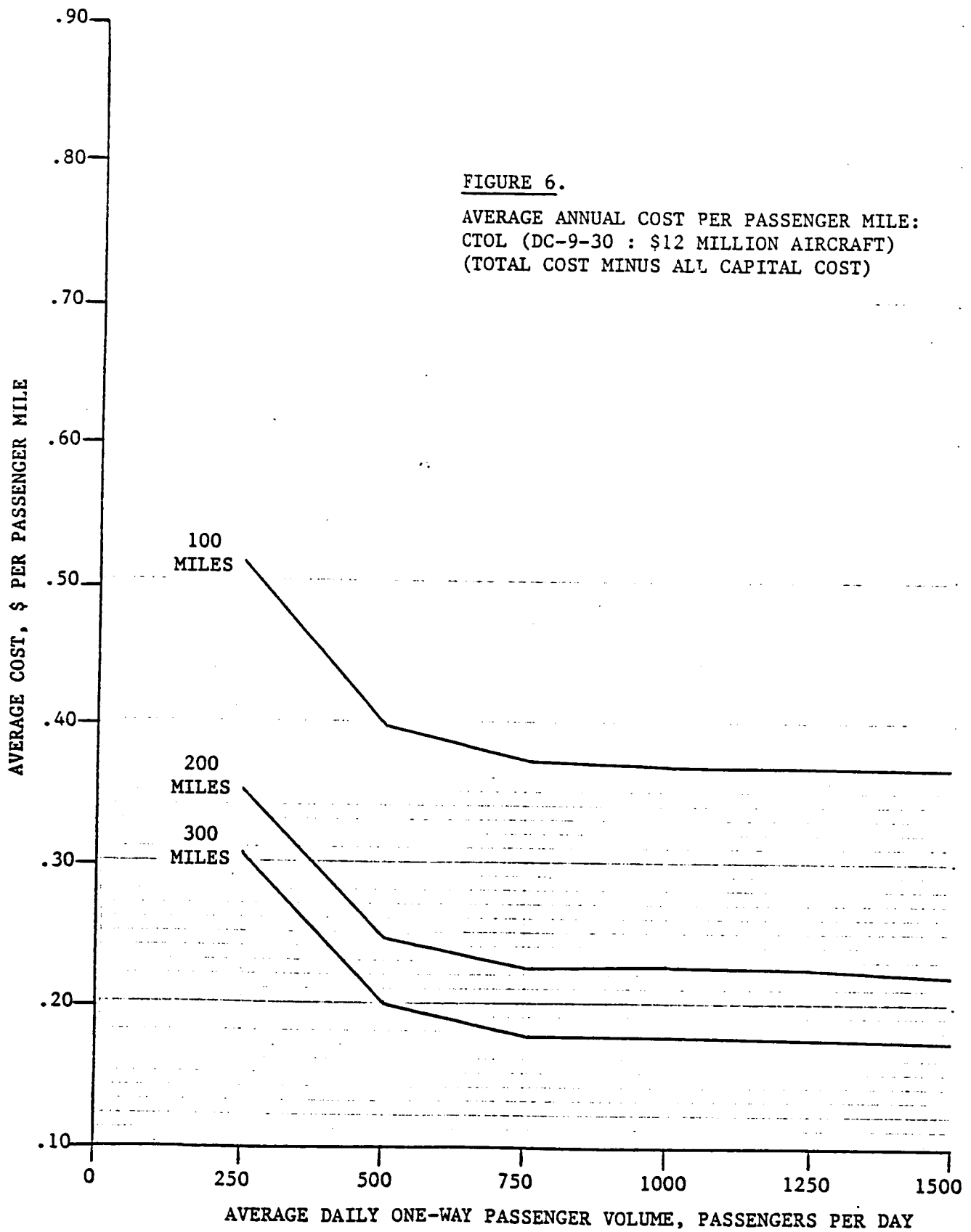


TABLE 7. CTOL system costs and characteristics vs. stage length and passenger volume.

Stage Length, mi					
Directional			Directional		
Passenger	Fleet		Headways	Terminal Cost	Total
Volume,	Size,		Hrs./Dep.	Per Passenger,	Cost
Pass./day	Vehicles	Peak	Base	\$/pass.	\$1000/yr.
<hr/>					
<u>100 miles</u>					
500	3	1	2	27.70	16,440
1000	3	1	2	27.70	21,620
1500	3	1	1.5	27.70	27,490
2000	3	0.8	1.09	27.70	34,051
2500	3	0.67	0.86	27.70	40,611
3000	5	0.57	0.75	27.70	52,032
 <u>200 miles</u>					
500	3	1	2	27.70	19,890
1000	3	1	2	27.70	25,070
1500	3	1	1.5	27.70	31,631
2000	5	0.8	1.09	27.70	44,770
2500	5	0.67	0.86	27.70	52,718
3000	5	0.57	0.75	27.70	59,968
 <u>300 miles</u>					
500	5	1	2	27.70	28,546
1000	5	1	2	27.70	33,727
1500	5	1	1.5	27.70	40,977
2000	5	0.8	1.09	27.70	50,298
2500	5	0.67	0.86	27.70	59,618
3000	7	0.57	0.75	27.70	73,110

### 3.5. SENSITIVITY ANALYSIS

While the model for CTOL aircraft was based on the established technical background of several years of operation of the DC-9-30 aircraft, and the parameter values used were thought to be relatively accurate, a sensitivity analysis was conducted to investigate what changes in the model would have a significant effect on passenger mile cost. Similar to the sensitivity analysis which was performed on the VTOL model, the parameters investigated were aircraft cost, aircraft speed, crew cost, direct maintenance cost, fuel cost, interest rates, load factors, terminal cost, and aircraft turn-around times. Table 8 presents a summary of the sensitivity analysis performed for the DC-9-30 aircraft representing CTOL technology.

Aircraft Cost: Changes in aircraft cost are moderately sensitive for the CTOL technology. The effect on passenger mile cost is relatively significant at lower passenger demands, but not too significant at the higher passenger volumes.

Vehicle Speed: The effect of varying aircraft speed was insignificant at some stage lengths and passenger demands, but very significant at others. The reason for significant changes is that vehicle speed had an effect on fleet size at these stage lengths and demands. Aircraft speed also influences the number of annual flight hours which was a factor in calculating several of the cost components in the CTOL model.

Crew Cost: Crew cost changed passenger cost very little and was judged to be a non-sensitive parameter.

Direct Maintenance: The effect of changing direct maintenance cost was also judged to be non-sensitive.

Fuel Cost: Changes in fuel expenditures had little influence on passenger mile cost. The minor effect which it did have, was more apparent at longer stage lengths.

Interest Rate: Changes in the interest rate effected passenger mile cost more significantly at low passenger demand volumes. Since the only capital expenditure in this model was the fleet investment the overall minor effect of this parameter is not surprising.

Load Factors: Reducing the maximum allowable load factors had no effect at low passenger volumes since there was excess capacity at these demands. However, the effect was significant at the longer stage lengths and higher passenger volumes. This was the result of more frequent aircraft operations and the cost associated with increasing fleet size.

Terminal Cost: Terminal passenger cost for the CTOL aircraft model appears to be an extremely sensitive parameter. It appears to be most significant at high passenger volumes and shorter stage lengths.

Turn-around Time: Turn-around time was not a significant factor for most stage lengths or passenger volumes. This is similar to the effect which was observed for differences in aircraft speed where different turn-around times may influence fleet size requirements.

TABLE 8. SENSITIVITY ANALYSIS FOR CTOL (DC-9-30)  
% CHANGE IN COST PER PASSENGER MILE

COST	VEH. COST (-45.5%)	VEH. SPEED (-20%)	CREW COST (-20%)	DIR. MAINT. (-20%)	FUEL COST (-20%)	INT. RATE (-20%)	LOAD FACTOR (-10%)	TERM. COST (-20%)	T.A. TIME (+25%)
STAGE LENGTH	AVG. DAILY PASSENGERS								
1	100	500	-21.60	+4.41	-0.79	-0.54	-2.19	-5.40	0.00
		3000	-11.38	+3.20	-0.59	-0.40	-1.60	-2.84	0.00
	200	500	-17.86	+33.46	-1.30	-0.90	-3.60	-4.46	+26.19
		3000	-9.86	+5.55	-.99	-0.66	-2.74	-2.45	0.00
	300	500	-20.73	+7.59	-1.38	-0.94	-3.78	-5.18	0.00
		3000	-11.37	+6.83	-1.26	-0.85	-3.41	-2.83	0.00
2	100	500	-3.42	+7.74	-1.41	-0.96	-3.85	-10.83	0.00
		3000	-1.31	+4.14	-0.74	-0.52	-2.04	-15.10	0.00
	200	500	-2.48	+14.99	-2.03	-1.40	-5.63	-7.91	+3.66
		3000	-1.09	+6.92	-1.23	-0.82	-3.41	-12.61	0.00
	300	500	-3.18	+13.02	-2.33	-1.61	-6.43	-6.03	0.00
		3000	-1.34	+8.83	-1.63	-1.10	-4.42	-10.75	0.00

1. TOTAL COST
2. TOTAL COST EXCLUDING ALL CAPITAL COST

#### 4. THE HSR COST MODEL

The rail cost model develops a cost relationship for the construction and operation of a short-haul intercity rail passenger service utilizing a fleet of high speed rail (HSR) trains. The cost are separated into two categories; those costs which are associated with major capital expenditures, and those costs which accrue as a direct result of train operation and service.

##### 4.1. MAJOR CAPITAL EXPENDITURES

These are expenses associated with the long-term investment of capital into track, and new terminal facilities. For purpose of this study, vehicle equipment is considered a variable cost rather than a major capital expenditure since vehicles can be resold. The annual cost for capital investments is calculated by multiplying their initial cost by an appropriate capital recovery factor (CRF).

##### Track and Roadbed Upgrading

It is necessary to upgrade existing track and roadbed to accommodate high speed service(i.e. install new rail, surfacing and lining of track, replacement of cross ties, reballasting and upgrading the roadbed, changes in alignment). These costs, of course, are very dependent on the amount of upgrading to be undertaken. In a 1983 publication printed by the Office of Technology Assessment titled, "U.S. Passenger Rail Technologies", it was stated that using existing right-of-way with major upgrading, could cost \$4.5 million to \$6 million per route mile with two tracks per route. These costs are assumed to include all costs for new electrification of an existing facility such as those associated with catenary with supports, substations and switching stations, supply lines, signaling and block station systems, and communication systems. The annual cost to upgrade

track is calculated as follows:

$$TER = 0.15230 \times \$4.5 \text{ million} \times \text{stage length}$$

$$\text{where CRF} = 0.15230$$

$$\text{cost per route mile} = \$4.5 \text{ million}$$

$$\text{stage length} = \text{one-way air distance stage length} \\ \text{multiplied by 14\% curcuity factor.}$$

#### New Terminal Facilities

In recent years, there has been very little new rail terminal construction, especially of major terminals in urban areas. This model assumes that an existing terminal will be used since most major cities have an AMTRAK terminal. Many of these have been renovated as part of AMTRAK's capital improvement program, and a few new terminals have been built. These have been paid for as part of federal (and sometimes state and local) appropriations for rail passenger service, and represent sunk costs. Therefore, no annual cost for such capital expenditure will be charged to HSR service. Variable costs associated with the operation of terminals will be included in the analysis, however, as additional trains and passengers will generally increase terminal maintenance and operating costs.

#### 4.2. VARIABLE COST

These are the costs which are directly associated with the actual operation of the trains and accompanying service. All costs are assumed to be linear in the explaining output variables; and with the exception of way and structure costs, all operating costs are assumed to be zero when output is zero.

#### Vehicles

The type of cars used are the ones most frequently used for passenger service in the United States. Only snack and coach cars are considered in this study for comparison with the type of service offered by the air modes. A standard coach has a seating capacity of 80



passengers, and a snack coach has a seating capacity of 64 passengers. Trains can be run with a minimum of one locomotive and one coach up to a maximum of one locomotive and ten coaches. Coach costs were estimated at \$650,000 per car (Ernst, Robert, The Budd Co., as referenced in Marchetti, 1984), while locomotives such as the AEM-7, a new high speed, light weight, electric passenger locomotive (Ephraim, 1981), were estimated to cost not less than \$1 million each. The annual fleet investment cost is based on a 15% interest rate and a maximum expected life of 30 years.

$$ACTI = CRF \times (\$1,000,000 (L) + \$650,000 (C))$$

where:  $CRF = 0.15230$

L is the number of locomotives necessary to operate service

C is the number of coach cars necessary to operate service

#### Transportation Operating Costs

These are costs incurred as a direct result of operating the train service. These costs include crew, fuel, and switching operations and are computed on the basis of train miles and car miles. The relationships for this part of the analysis were developed entirely by updating similar relationships from the 1972 DOT Report. The coefficients in these equations were updated to 1982 dollars by multiplying them by the appropriate railroad cost recovery index (Association of American Railroads Yearbook, 1983).

The updated cost relationships are:

- (1) Electric Power (Fuel):  $EP = \$0.4286 \times CM$
- (2) Block Station:  $BS = \$0.5247 \times TM$
- (3) Division Operator:  $DO = \$0.2501 \times TM$
- (4) Yard and Switching:  $YAS = \$0.2064 \times TM$
- (5) Asst. Superintendant of Passenger Transportation:  $ASPT = \$0.1817 \times TM$

Crew costs, which are a part of transportation operating cost, were based on three crewmen for a one car train and one crewman for each additional two cars added. The updated equation for crew cost is:

$$TRC = \$2.2945 \times TM + \$0.3047 \times CM$$

#### Maintenance of Equipment Cost

These are all the cost associated with the maintenance of the locomotives and coaches including labor, material, insurance, and building rental. The costs are functions of train miles and car miles. Cost relationships were updated resulting in the following equation:

$$DME = \$1.1469 \times TM + \$0.3105 \times CM$$

#### Maintenance of Way and Structure

These costs include all maintenance of track, structures, and communications signals. The costs are explained on the basis of a fixed component per route mile and a variable component per gross ton mile of the system. The updated relationship from the 1972 DOT report is as follows:

$$DMWS = \$31,873 \times SL + \$0.00608 \times GTM$$

where: GTM = annual gross ton miles

The gross weight of a locomotive is based on the AEM-7 locomotive which equals 100 tons (Ephraim, 1981), and a standard coach which has a fully loaded weight of 60 tons.

Therefore, annual gross ton miles are calculated as follows:

$$GTM = 100 \times TM + 60 \times CM$$

#### Terminal Operating Costs:

These are the costs incurred as a direct result of operating a terminal facility. All costs for an existing urban terminal, with the exception of stationmaster expense, are explained on the basis of number of passengers utilizing the system. Station maintenance is included here rather than

under maintenance of way and structures in order to keep all terminal expenses together. The following cost relationships have been updated for an existing urban terminal:

Ticket Sales:	$UTSO = \$0.6750 \times BNSP$
Station Utilities:	$UTIL = \$0.2321 \times BNSP$
Station Cleaning:	$CLEN = \$0.1428 \times BNSP$
Station Maintenance: .	$SMAIN = \$0.1652 \times BNSP$
Station Master:	$SMA = \$0.4969 \times TM$

#### 4.3 TOTAL COST EQUATIONS

The purpose of this section is to present the components which comprise each of the HSR total cost equations and the cost per passenger mile equation corresponding to each one. Additionally, in Table 9, updated cost parameters used in the model are summarized by identifying the source and value of the original factor, and then stating the factor and source used to update this parameter to its present value.

##### 1. Average Annual Total Cost (TAAC):

###### Major Capital Expenditures:

-Track and Roadbed Upgrading (TER) =  $0.15230 \times \$4.5 \text{ million} \times \text{SL}$

###### Variable Cost:

-Fleet Investment (ACTI) =  $\text{CRF} \times (\$1,000,000 (\text{L}) + \$650,000 (\text{C}))$

###### Transportation Operating Cost:

1. Electric Power (EP) =  $\$0.4286 \times \text{CM}$

2. Block Station (BS) =  $\$0.5247 \times \text{TM}$

3. Division Operator (DO) =  $\$0.2501 \times \text{TM}$

4. Yard and Switching (YAS) =  $\$0.2064 \times \text{TM}$

5. Asst. Superintendant of Passenger Transportation (ASPT) =  $\$0.1817 \times \text{TM}$

6. Crew Costs (TRC) =  $\$2.2945 \times \text{TM} + \$0.3047 \times \text{CM}$

-Maintenance of Equipment (DME) =  $\$1.1469 \times \text{TM} + \$0.3105 \times \text{CM}$

-Maintenance of Way and Structure (DMWS) =  $\$31,873 \times \text{SL} + \$0.00608 \times \text{GTM}$

###### Terminal Operating Cost:

1. Ticket Sales (UTSO) =  $\$0.6750 \times \text{BNSP}$

2. Station Utilities (UTIL) =  $\$0.2321 \times \text{BNSP}$

3. Station Cleaning (CLEN) =  $\$0.1428 \times \text{BNSP}$

4. Station Maintenance (SMAIN) =  $\$0.1652 \times \text{BNSP}$

5. Station Master (SMA) =  $\$0.4969 \times \text{TM}$

$\text{TAAC} = \text{TER} + \text{ACTI} + \text{EP} + \text{BS} + \text{DO} + \text{YAS} + \text{ASPT} + \text{TRC} + \text{DME} + \text{DMWS} + \text{UTSO} + \text{UTIL} + \text{CLEN} + \text{SMAIN} + \text{SMA}$

The cost per passenger mile based on total cost is calculated as follows:

$$\text{PPCUU} = \frac{\text{TAAC}}{\text{SL} \times \text{BNSP}}$$

2. Average Annual Total Cost Excluding Fixed Facility Capital Cost (TALC):

This cost is equal to the total cost excluding the major capital expenditure of track and roadbed upgrading.

$$TALC = TAAC - TER$$

The cost per passenger mile based on total cost excluding fixed facility capital cost is calculated as follows:

$$PPUUV = \frac{TALC}{SL \times BNSP}$$

3. Average Annual Total Cost Excluding All Capital Cost (TALCAV):

This cost is equal to the total cost excluding fixed facility cost calculated above, minus the annual fleet investment.

$$TALCAV = TALC - ACTI$$

The cost per passenger mile based on total cost excluding all capital cost is calculated as follows:

$$PPWOV = \frac{TALCAV}{SL \times BNSP}$$

TABLE 9. Summary of Updated Cost Parameters:

Unit Cost Parameter	Parameter Value (Year)	Source of Original Parameter	Updating Factor	Source of Updating Factor	Parameter Value (1982)
Transportation					
Operating Costs:					
(1) Electric Power	\$0.1522 (1972)	"	2.82	p. 493 U.S. Statistical Abstract, 1984	\$0.4286
(2) Block Station	\$0.2171 (1972)	"	2.42	p. 59 Association of American Railroads Year Book (1983)	\$0.5247
(3) Division Operator	\$0.1035 (1972)	"	2.42	"	\$0.2501
(4) Yard & Switching	\$0.0854 (1972)	"	2.42	"	\$0.2064
(5) Asst. Superintendent of Pass. Transp.	\$0.0752 (1972)	"	2.42	"	\$0.1817
(6) Crew Costs	\$0.8381 (1972)	"	2.74	"	\$2.2945
	\$0.1113 (1972)	"	2.74	"	\$0.3047
Maintenance of Equipment Costs	\$0.4096 (1971)	"	2.80	"	\$1.1469
	\$0.1109 (1971)	"	2.80	"	\$0.3105
Maintenance of Way and Structure	\$10980 (1970)	"	2.90	"	\$31,873
	\$0.002094 (1970)	"	2.90	"	\$0.00608
Terminal Operating Costs:					
(1) Ticket Sales	\$0.2793 (1972)	"	2.42	"	\$0.6750
(2) Station Utilities	\$0.0898 (1972)	"	2.42	"	\$0.2321
(3) Station Cleaning	\$0.0591 (1972)	"	2.42	"	\$0.1428
(4) Station Maintenance	\$0.0639 (1972)	"	2.42	"	\$0.1652
(5) Station Master	\$0.2056 (1972)	"	2.42	"	\$0.4969

#### 4.4. COST PER PASSENGER MILE

The purpose of this section is to present the cost per passenger mile and output capabilities from the high speed rail cost model. These different values were calculated for the cost per passenger mile. These were based on the following:

- 1) Total cost (see Figure 7)
- 2) Total cost minus fixed facility capital cost (see Figure 8)
- 3) Total cost minus all capital cost (see Figure 9)

The costs per passenger mile for each of these calculations are summarized in Tables 10 and 11. Figure 7 shows a graph of average cost per passenger mile based on total cost, versus average one-way daily passenger volumes. The cost is influenced almost entirely by the cost component of track and roadbed upgrading, and the cost per passenger mile is tremendously high. When all costs are considered frequency of train operation has very little significance as observed by the small difference in passenger mile cost between the two frequencies considered (the service which is slightly more expensive operates twice as many trains). Changes in stage length resulted in insignificant changes in cost which is not surprising since the major cost component is assessed by the mile. Obviously, the more passengers there are on the system, the less costly it is per passenger.

Figure 8 shows a graph of average cost per passenger mile based on total cost excluding fixed facility capital cost, versus average one-way daily passenger volumes. Eliminating the cost component for track upgrading reduces costs by as much as 400%. Again, costs per passenger decreases as daily passenger volume increases. Also, the difference in costs for different stage lengths is not significant, but frequency of train operation does become significant.

Figure 9 shows a graph of average cost per passenger mile based on total cost excluding all capital cost, versus average one-way daily passenger volumes. Costs are slightly lower than those observed in Figure 8, since car and locomotive costs have been eliminated. Additionally, stage lengths do not effect cost per passenger mile, but frequency and passengers volumes do.

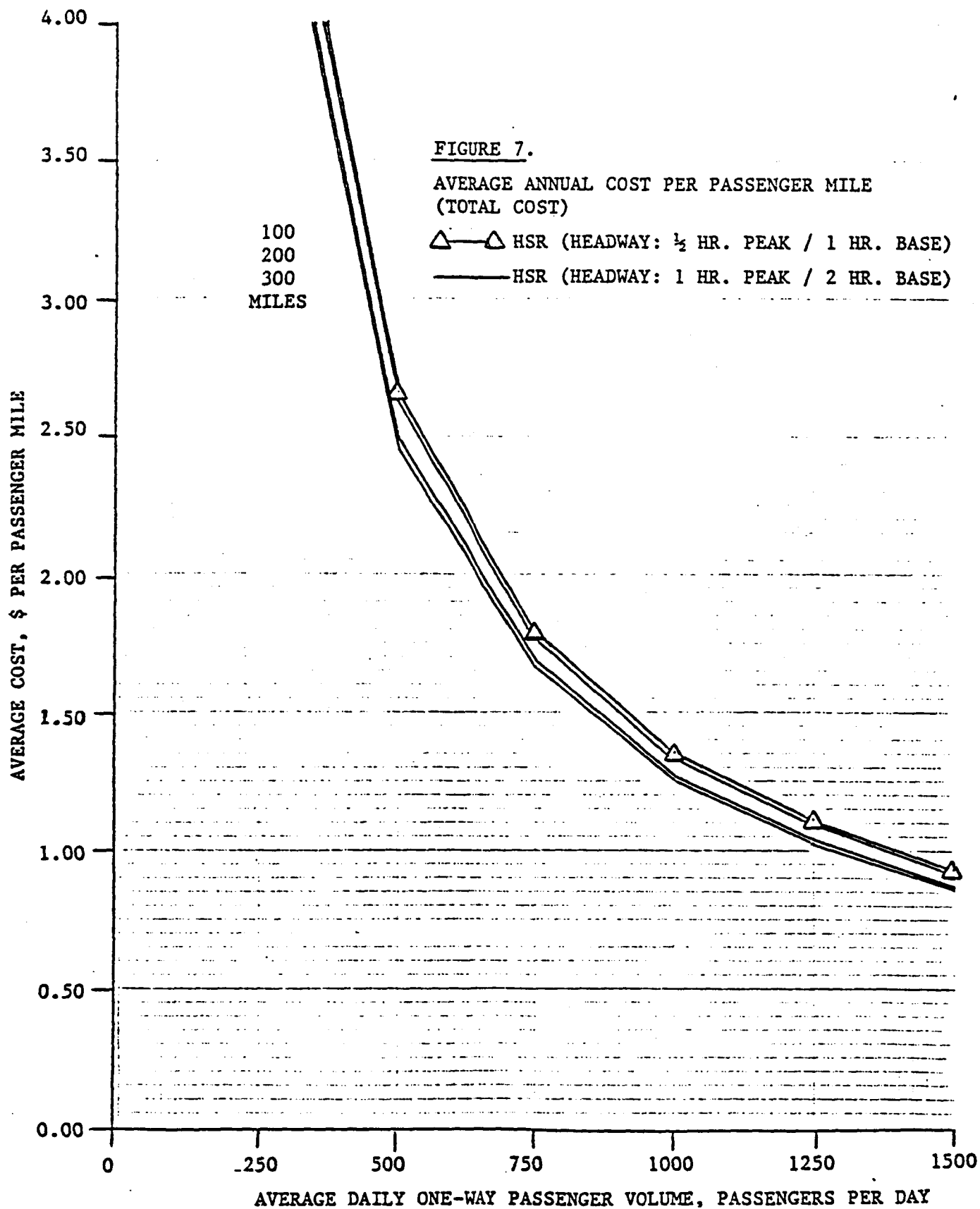


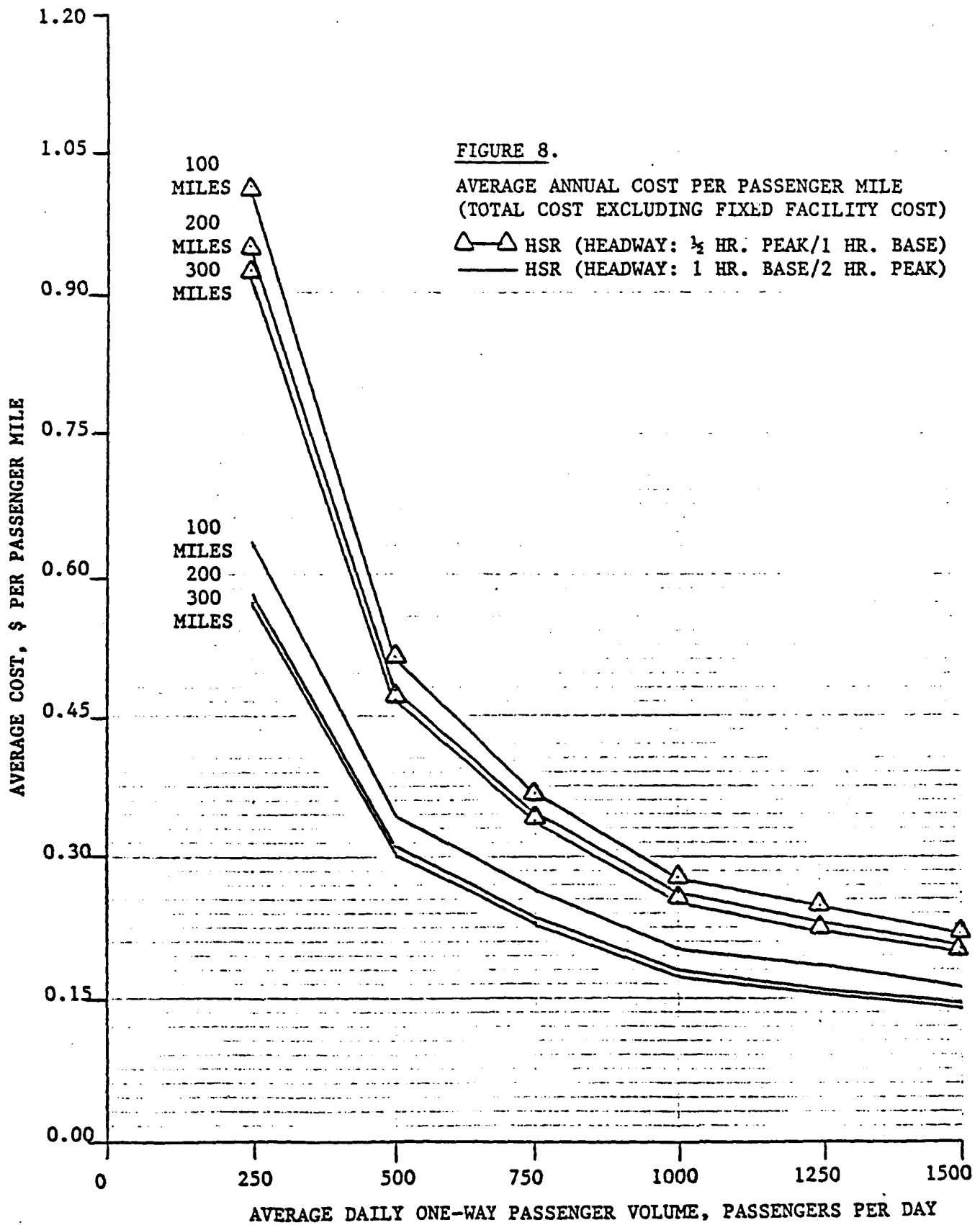
TABLE 10. High speed rail costs per passenger mile vs. stage length and passenger volume, with directional headways of 1.0 hour/departure in peak and 2.0 hours/departure in base period.

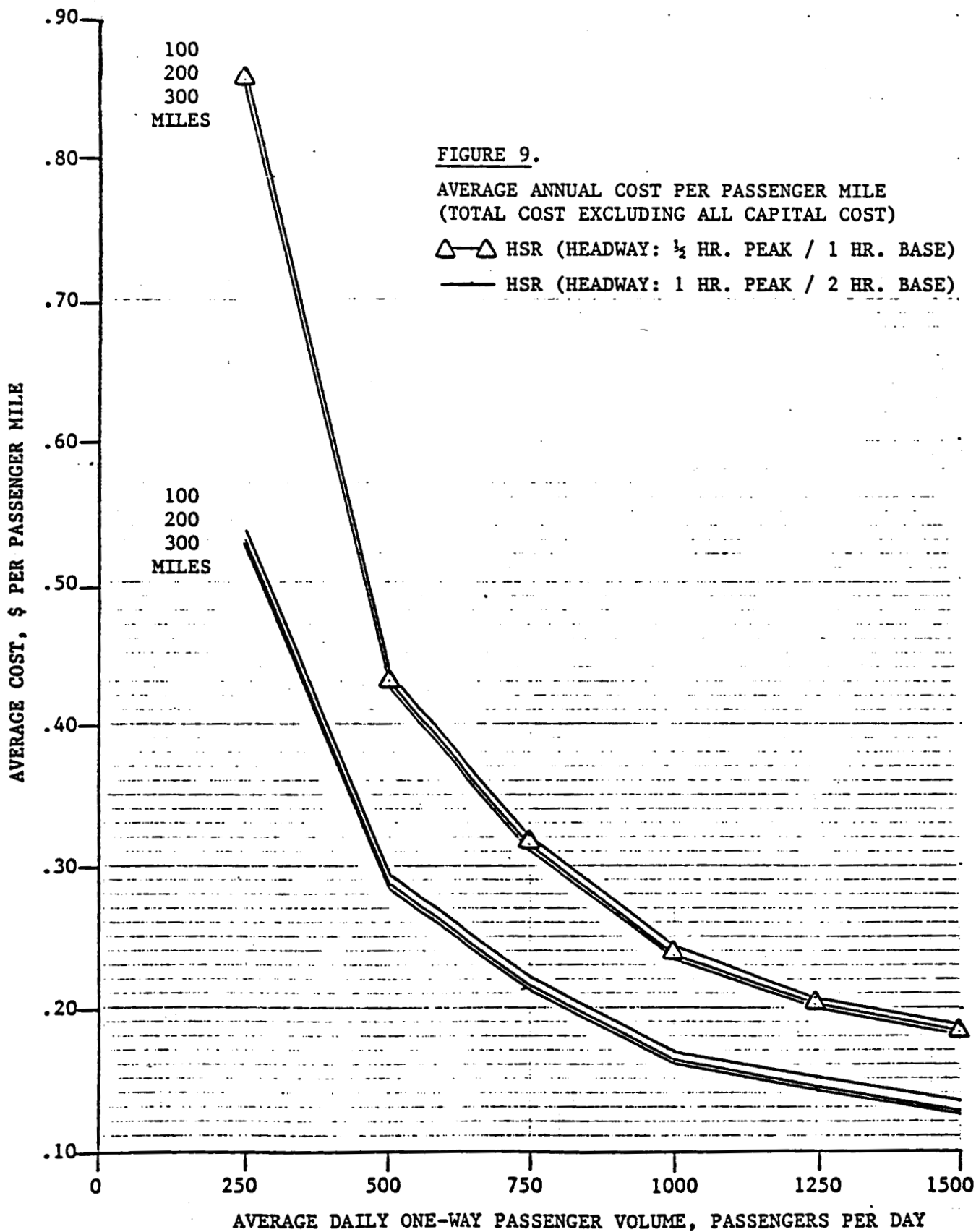
Stage Length	Average Cost, \$/Pass. Mile		
Directional Passenger Volume, Pass./Day	Total Cost	Total Cost Minus Fixed Facility Costs	Total Cost Minus All Capital Cost
<hr/>			
<u>100 miles</u>			
250	4.9136	.6322	.5358
500	2.4821	.3414	.2933
750	1.6929	.2658	.2210
1000	1.2727	.2024	.1688
1250	1.0399	.1837	.1503
1500	.8751	.1615	.1337
 <u>200 miles</u>			
250	4.8593	.5779	.5297
500	2.4520	.3113	.2872
750	1.6644	.2373	.2149
1000	1.2498	.1795	.1627
1250	1.0172	.1609	.1442
1500	.8551	.1415	.1276
 <u>300 miles</u>			
250	4.8504	.5690	.5277
500	2.4465	.3058	.2852
750	1.6592	.2321	.2129
1000	1.2454	.1751	.1607
1250	1.0132	.1570	.1422
1500	.8515	.1379	.1256

TABLE 11. High speed rail costs per passenger mile vs. stage length and passenger volume, with directional headways of 0.5 hours/departure in peak and 1.0 hour/departure in base period.

<u>Stage Length, mi.</u>		Average Cost, \$/Pass. Mile	
Directional Passenger Volume, Pass./Day	Total Cost	Total Cost Minus Fixed Facility Cost	Total Cost Minus All Capital Cost
<hr/>			
<u>100 miles</u>			
250	5.2933	1.0119	.8604
500	2.6527	.5120	.4363
750	1.7946	.3675	.3206
1000	1.3490	.2786	.2435
1250	1.1060	.2497	.2075
1500	.9347	.2212	.1878
 <u>200 miles</u>			
250	5.2321	.9507	.8543
500	2.6191	.4784	.4302
750	1.7738	.3466	.3145
1000	1.3319	.2615	.2374
1250	1.0840	.2277	.2014
1500	.9172	.2036	.1817
 <u>300 miles</u>			
250	5.2071	.9257	.8523
500	2.6056	.4649	.4282
750	1.7641	.3370	.3125
1000	1.3241	.2537	.2354
1250	1.0758	.2195	.1994
1500	.9100	.1964	.1797







#### 4.5. SENSITIVITY ANALYSIS

A sensitivity analysis was conducted to investigate if changes in certain model parameters would have a significant effect on passenger mile cost. The analysis examined frequency of operation, fuel cost, interest rates, load factors, track upgrading cost, and vehicle cost. Table 12 presents a summary of the sensitivity analysis performed for the tilt-rotor technology. The format is identical to that used in Table 4.

Frequency: When total cost is considered frequency of train operations become insignificant as all costs are dominated by the track upgrading cost component. For the other costs measures considered, frequency is a significant factor. Running trains more often at lower passenger volumes has a greater effect on these costs than running trains more often at higher passenger volumes, and the same effects are observed regardless of stage length.

Fuel Cost: Fuel cost (electricity) changed passenger cost very little and was judged to be a non-sensitive parameter.

Interest Rate: Since the majority of total cost is due to the major expenditure for track upgrading, interest rates are extremely sensitive. When the track upgrading component was eliminated from the cost per passenger mile calculations, interest rates were basically insignificant.

Load Factors: Reducing the maximum allowable load factors had absolutely no effect for the high frequency (headway 1/2 hr. peak/1 hr. base) since there was excess capacity under this operating scheme. For the lower frequency (headways: 1 hr. peak/2 hr. base) there was excess capacity at the 500 passenger volume and costs were not effected. For demands greater than this costs were affected since more train operations and larger fleet sizes were required to satisfy demand. Of course, for total cost the effect was minimal as previously explained. For the other costs considered, reducing maximum allowable load factors was relatively significant.

Track and Roadbed Upgrading: Since this cost component represents such a large proportion of total cost, it is not surprising that this parameter is extremely sensitive to change. This component was excluded for the other two cost categories considered, so it did not effect them.

Vehicle Cost: Changes in vehicle cost had caused little change in passenger mile cost and was generally judged to be a non-sensitive parameter. The minor effect that it did have was more apparent at shorter stage lengths.

TABLE 12. SENSITIVITY ANALYSIS FOR HIGH SPEED RAIL  
% CHANGE IN COST PER PASSENGER MILE

COST	STAGE LENGTH	AVG. DAILY PASSENGERS	FREQ. (-100%)	FUEL COST (+10.64%)	INT. RATE (-20%)	L.F. 8-12 FREQ (-10%)	L.F. 16-24 FREQ (-10%)	TRACK UPGRADE (+10%)	VEH. COST (+100%)
1	100	500	-7.17	+0.08	-15.49	0.00	0.00	+8.08	+2.86
		3000	-6.38	+0.19	-14.77	+1.21	0.00	+7.63	+3.57
	200	500	-7.13	+0.08	-15.47	0.00	0.00	+8.18	+1.84
		3000	-6.77	+0.20	-14.83	+0.87	0.00	+7.77	+2.40
	300	500	-6.85	+0.08	-15.47	0.00	0.00	+8.22	+1.41
		3000	-6.43	+0.20	-14.85	+0.82	0.00	+7.84	+1.85
	2	500	-37.52	+0.41	-2.77	0.00	0.00	0.00	+14.96
		3000	-26.99	+0.80	-2.80	+4.24	0.00	0.00	+15.05
		500	-39.21	+0.44	-1.87	0.00	0.00	0.00	+10.14
3	100	500	-38.53	+0.45	-1.46	0.00	0.00	0.00	+7.94
		3000	-29.79	+0.92	-1.58	+5.08	0.00	0.00	+8.55
	200	500	-37.73	+0.49	0.00	0.00	0.00	0.00	0.00
		3000	-28.81	+0.96	0.00	+3.22	0.00	0.00	0.00
	300	500	-38.00	+0.49	0.00	0.00	0.00	0.00	0.00
		3000	-29.77	+0.99	0.00	+3.37	0.00	0.00	0.00
	300	500	-38.09	+0.48	0.00	0.00	0.00	0.00	0.00
		3000	-30.11	+1.00	0.00	+3.42	0.00	0.00	0.00

1. TOTAL COST
2. TOTAL COST EXCLUDING FACILITY CAPITAL COST
3. TOTAL COST EXCLUDING ALL CAPITAL COST



## 5. COMPARISON OF TECHNOLOGIES

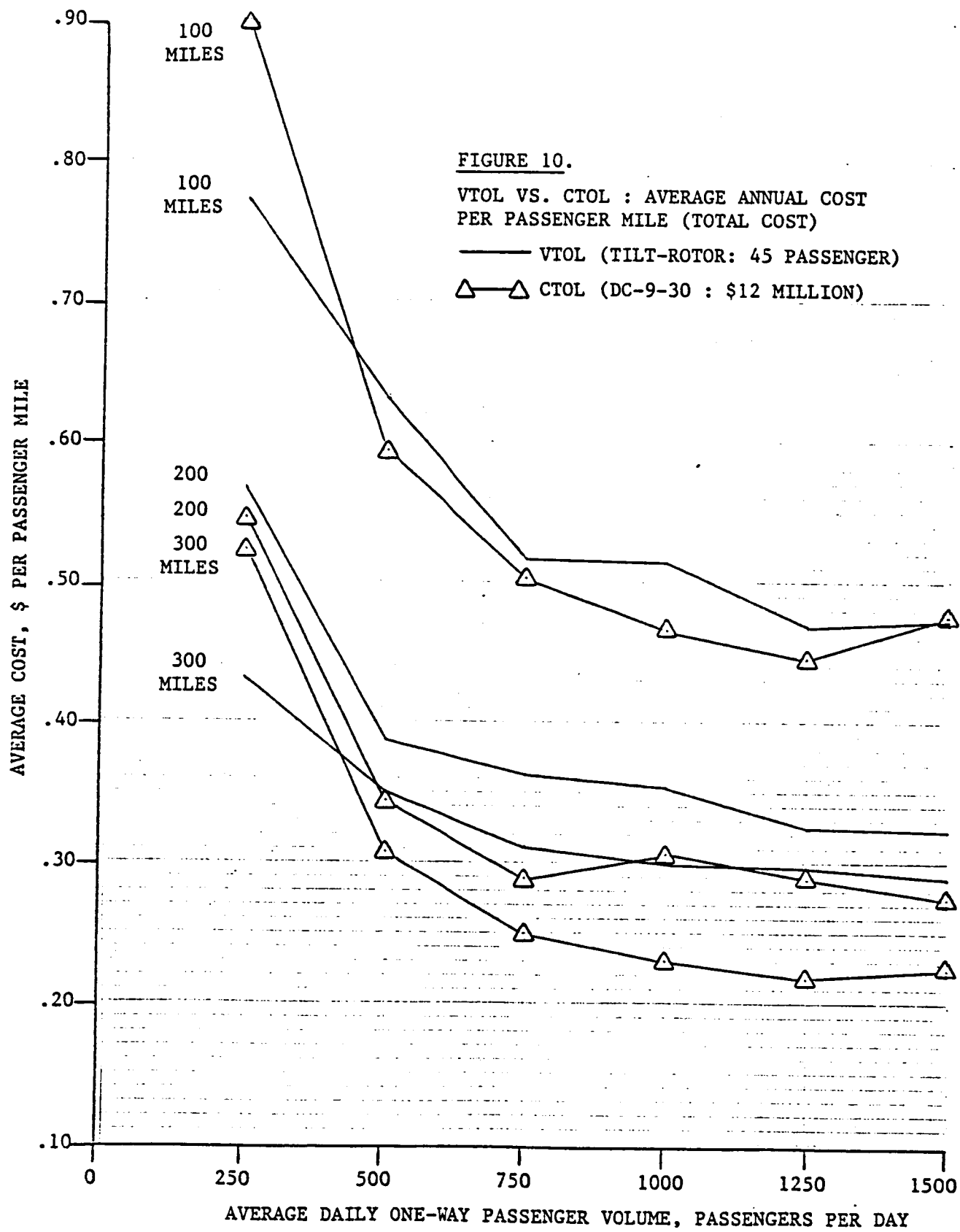
### 5.1. TILT-ROTOR AND CTOL

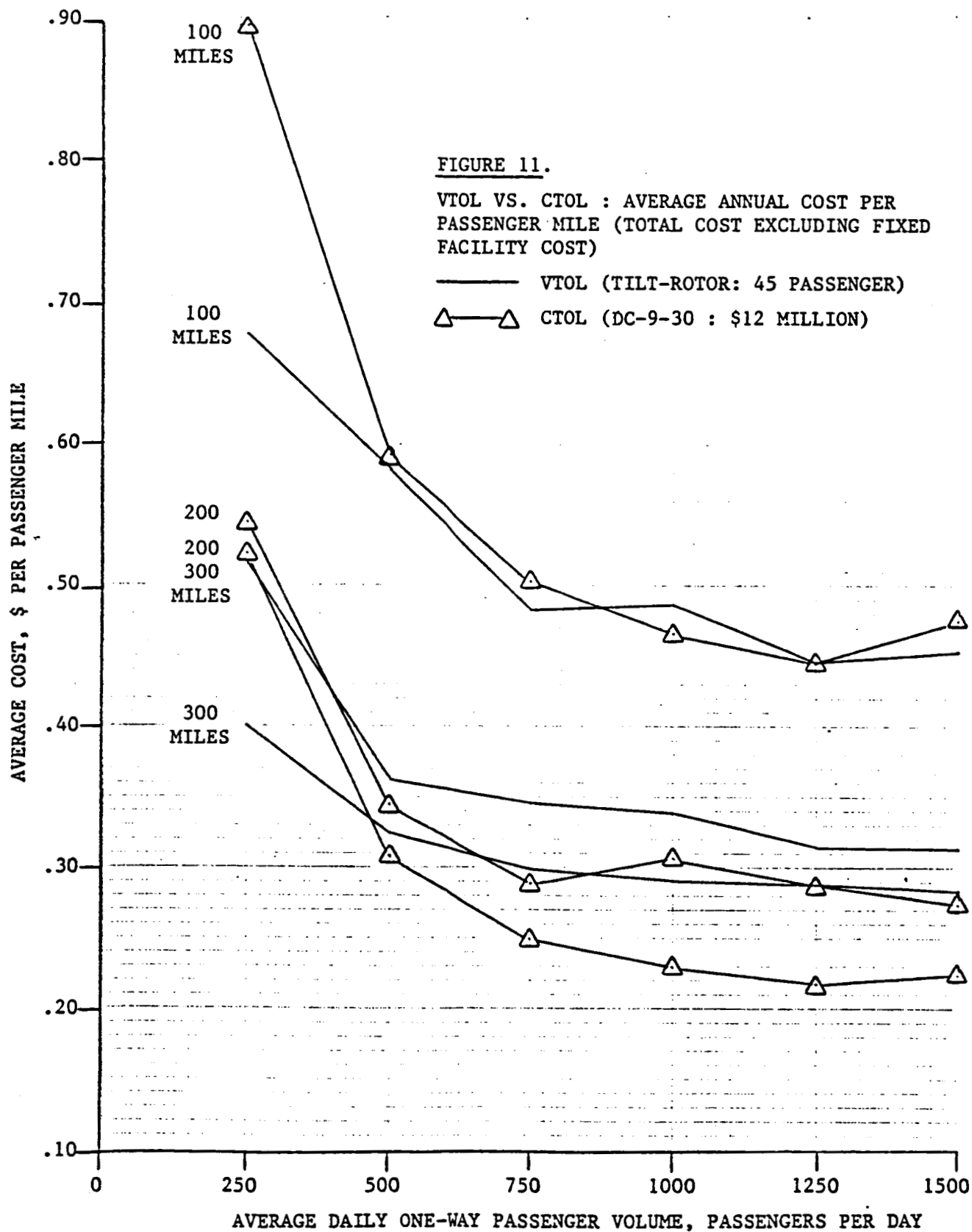
The purpose of this section is to present the results of the comparison of the two aircraft modes in terms of their cost and transport output capabilities. The individual cost per passenger mile for the 45 passenger tilt-rotor aircraft was presented in section II, and those for the CTOL technology were presented in section III.

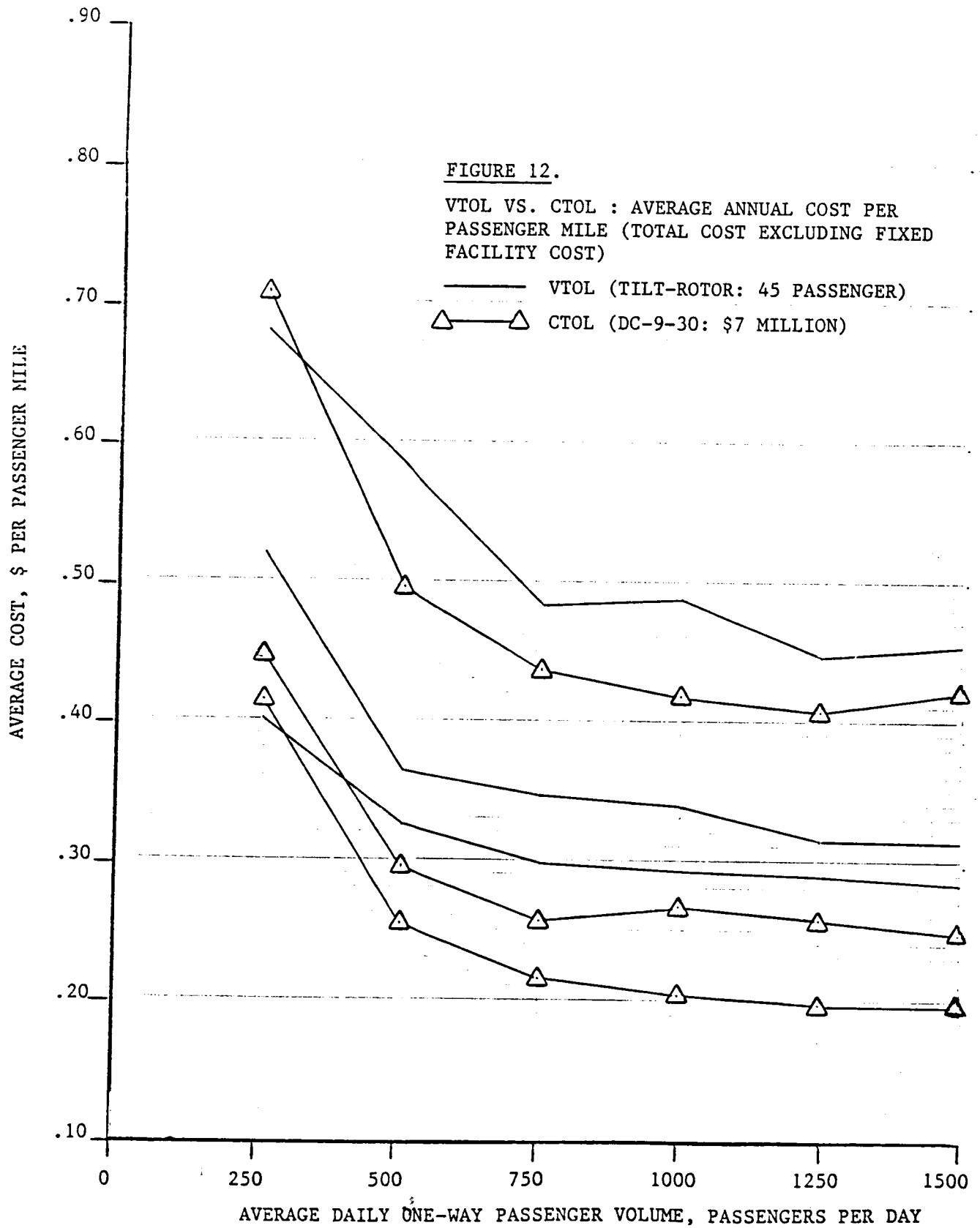
Figure 10 shows a graph comparing average cost per passenger mile based on total cost versus average one-way daily passenger volumes. At the 100 mile stage length VTOL technology has a lower cost per passenger mile until approximately the 500 one-way passenger volume. At volumes greater than this, the cost are very similiar. At the 200 mile stage length the CTOL cost is less than VTOL cost for all passenger volumes. For the 300 mile stage length, VTOL technology once again has a lower cost per passenger mile up until about the 500 passenger volume, but is more expensive for all passenger volumes exceeding this.

As previously stated, another appropriate cost per passenger mile to consider is the one based on total cost minus fixed facility capital cost, since many of these costs are typically financed by federal, state, and local governments, or other airport revenues, rather than charged directly to an airline. The VTOL cost per passenger mile minus fixed facility cost will be compared to the CTOL cost per passenger mile based on total cost. This is because the total cost calculations for CTOL assumed that no further construction of terminals and runways was required.

Figure 11 shows the comparison of these costs for tilt-rotor aircraft and a \$12<sup>+</sup> million CTOL aircraft. Figure 12 shows this comparison considering a \$7 million CTOL aircraft since it was stated in section III that DC-9-30 aircraft were available at this price on the resale market, and since the sensitivity analysis showed that aircraft cost was a moderately sensitive parameter, particularly at lower passenger volumes.







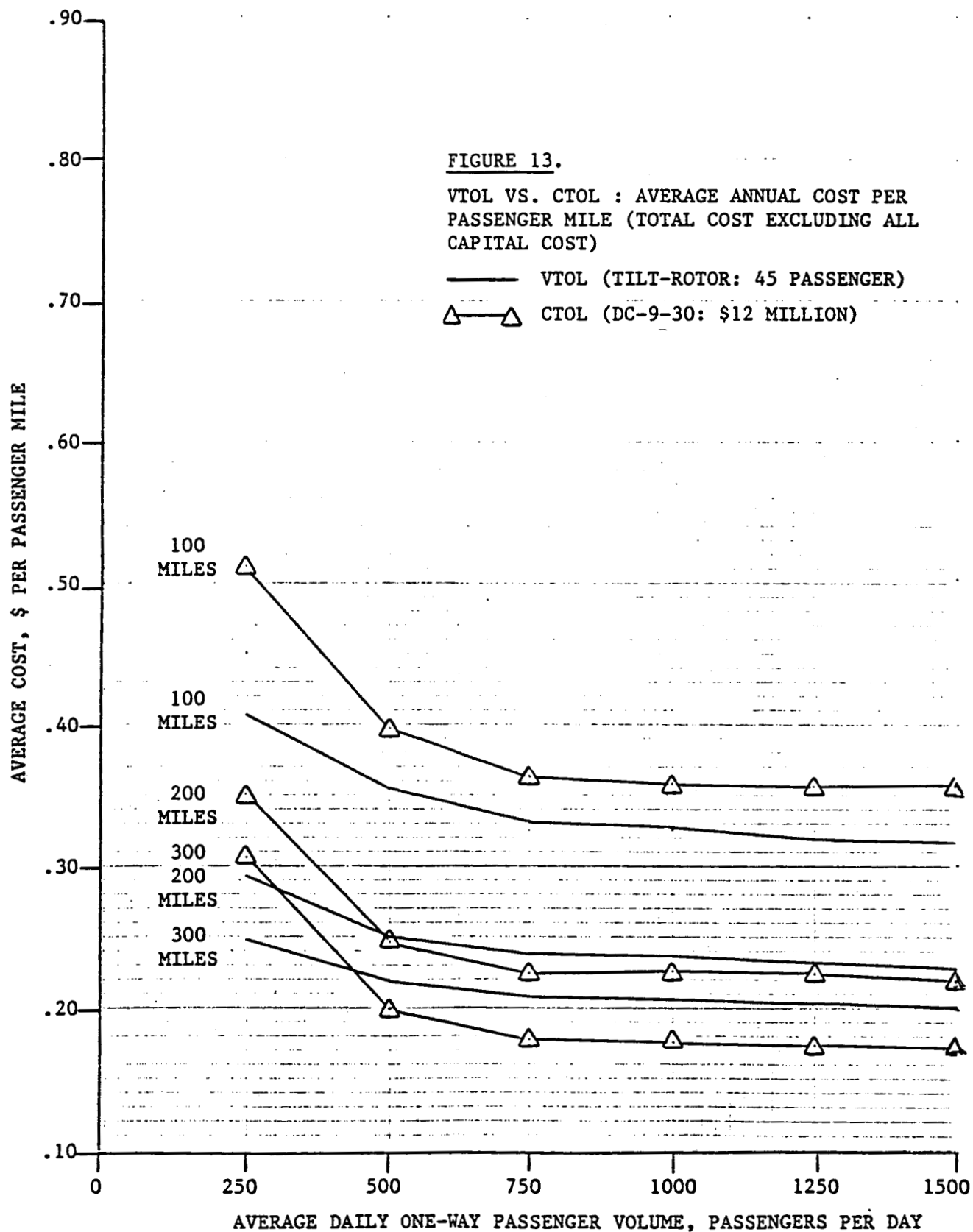
In Figure 11, VTOL costs are substantially less than CTOL costs for the 100 mile stage length up to the 500 passenger volume and very similar for all other passenger volumes. For the 200 mile stage length VTOL and CTOL costs are very similar up to the 500 passenger volume. At volumes greater than this, CTOL is always less expensive. For the 300 mile stage length, VTOL is less expensive than the CTOL up to the 500 passenger volume, and more expensive at passenger volumes greater than this.

When the \$7 million aircraft is considered as in Figure 12, CTOL technology appears much less expensive than VTOL technology for almost all stage lengths and passenger volumes. The costs are similar at very low passenger volumes for both the 100 and 300 mile stage lengths.

Figure 13 shows a comparison of average costs per passenger mile based on total cost excluding all capital cost. At the 100 mile stage length VTOL has the advantage over the entire range of passenger volumes. At the 200 mile stage length VTOL has a slight advantage up to the 500 passenger level. Beyond this point, costs per passenger mile are almost identical. At the 300 mile stage length VTOL is less expensive up until the 400 passenger level. At volumes greater than this, CTOL has a slight advantage over VTOL.

In summary, VTOL seems favorable, or at least competitive, up until about a one-way volume of 500 passengers, particularly at shorter stage lengths. This is attributable to the excess capacity of the DC-9-30 at low passenger volumes which result from the frequency of flights required to meet a specified minimum level of service.

Actually, output above the 1000 one-way passenger level may prove infeasible for the small tilt-rotor aircraft analyzed here. This level of demand would require departures at each terminal approximately every 20 minutes during peak periods and about every 26 minutes in base periods (see Table 3). While one of the primary reasons for introducing the tilt-rotor service may be to help alleviate the problem of air congestion, the impact of this number of aircraft movements would hardly do that.



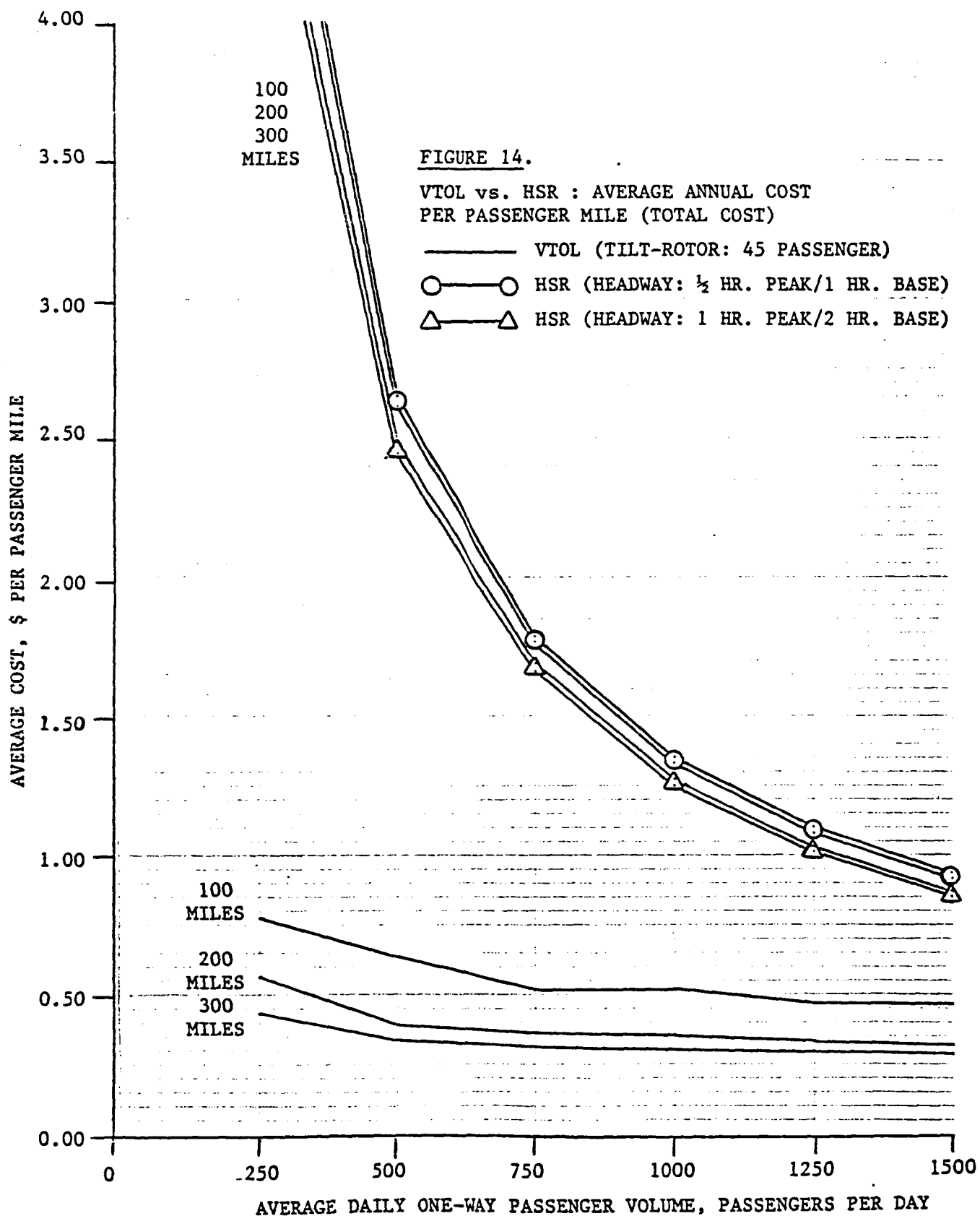
## 5.2. TILT-ROTOR AND HSR

The purpose of this section is to present the results of the comparison of tilt-rotor and HSR technologies in terms of their cost and transport output capabilities. The individual cost per passenger mile for the 45 passenger tilt-rotor aircraft was presented in section II, and those for the HSR technology were presented in section IV.

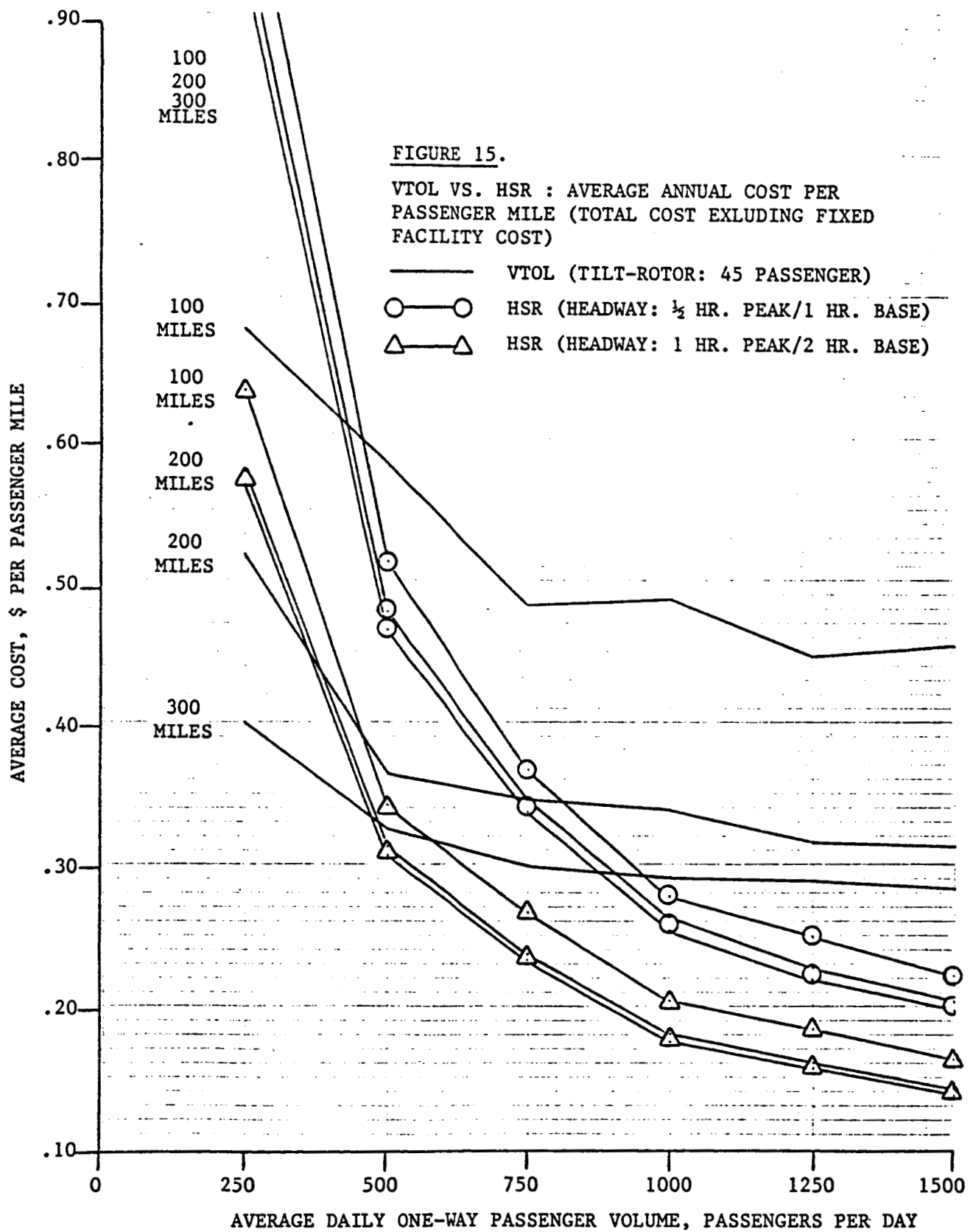
When average cost per passenger mile based on total cost are compared as in Figure 14, tilt-rotor technology appears much superior to the exorbitant cost of rail.

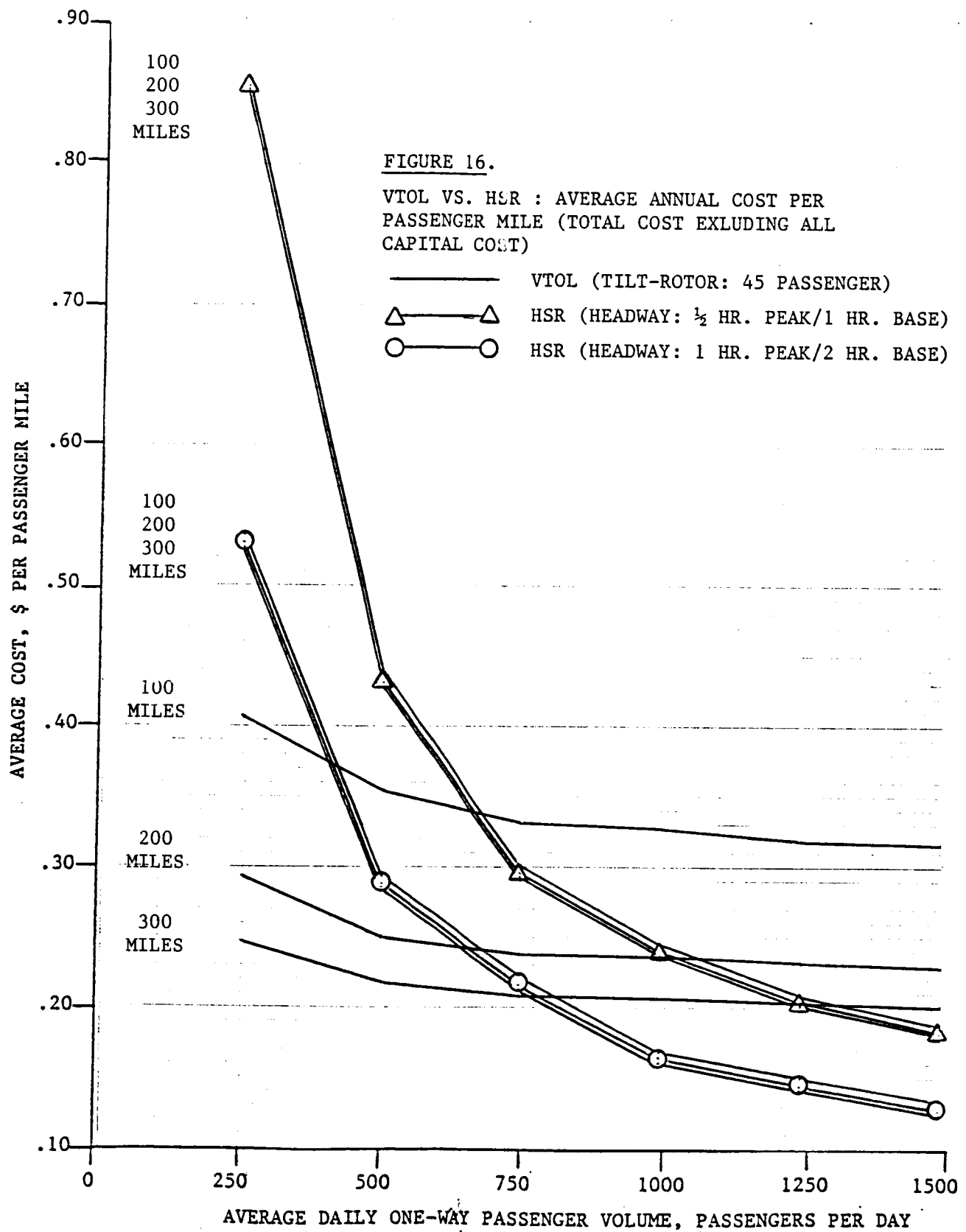
Figure 15 shows a graph comparing average cost per passenger mile based on total cost excluding fixed facility cost. This cost eliminates the major capital expenditure of track and roadbed upgrading and allows HSR to become much more competitive with tilt-rotor technology, particularly as passenger volumes increase.

Figure 16 shows a comparison of average cost per passenger mile based on total cost excluding all capital cost. As in the previous figure VTOL is less expensive than HSR at low passenger volumes. HSR becomes more competitive as passenger volumes increase.









## 6. CONCLUSIONS

It appears from this cost analysis that at low passenger volumes and particularly at shorter stage lengths tilt-rotor aircraft could compete with conventional aircraft. Unless HSR transportation is greatly subsidized, VTOL and CTOL technologies both seem much superior based on cost per passenger mile.

More accurate cost information will be available once the military tilt-rotor aircraft is produced and cost data gathered from its flight experience. This will allow for better estimates of the tilt-rotor potential to enter a market. The sensitivity analysis showed that the aircraft cost was particularly sensitive, therefore if tilt-rotor aircraft can be acquired at cost substantially lower than those estimated in the VTOL mode, total cost may be reduced and the aircraft may become more feasible.

While this analysis has compared VTOL, CTOL, and HSR technologies for a variety of passenger demands and stage lengths, the true feasibility of a tilt-rotor aircraft operation can only be determined by identifying and analyzing specific markets where this technology might be applicable.

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## APPENDICES

## APPENDIX A

### VTOL Cost Computer Program

This program, named "LINKTR", is the computerized version of the VTOL cost model. For every stage length, passenger flow, minimum allowable frequency and load factor specified in the data entries, the following calculations are performed and printed in the computer output:

- useable seats for both peaks and base periods
- actual aircraft frequency per period (number of daily departures in each period)
- annual direct cost (dollars)
- annual indirect cost (dollars)
- annual total cost (dollars)
- cost per passenger mile based on total cost
- cost per passenger mile based on total cost minus fixed facility capital cost
- cost per passenger mile based on total cost minus all capital cost
- fleet size
- terminal cost (dollars)

Note: Distances refer to airline distances.

The basic logic of the LINKTR program is outlined in the following steps:

1. Read data
2. Calculate passenger flows during peak and base periods
3. Calculate usable seats for specified minimum allowable frequency
4. Test whether usable seats generated from running at minimum allowable frequency satisfies peak demand
  - If demand is satisfied, go to step 5
  - If demand is not satisfied, increase frequency in order to satisfy demand; go to step 5

5. Repeat steps 3 and 4 for base period
6. Determine fleet size which enables operator to provide frequencies required to satisfy demand and level of service requirements
7. Calculate direct, indirect, and total costs
8. Calculate costs per passenger miles
9. Print output

\* DO LOOPS repeat above process for all stage lengths and capacities.

The application of the program was particularly useful in performing a sensitivity analysis of various parameters used in the model. For example, the following parameters were changed and their effect on annual cost and cost per passenger mile were observed: aircraft cost, aircraft speed, crew cost, direct maintenance, fuel cost, interest rate, load factors, terminal cost and turn-around times.

LINKTR

```

100 C INTERCITY PASSENGER MODES COST COMPARISON
110 C COST OF TILTROTOR OPERATING FROM EXISTING TERMINALS FOR
120 C A SINGLE LINK
130 C
140 C DIMENSION D(14,8)
150 C
160 C THIS SECTION READS THE DATA MATRIX INTO THE PROGRAM
170 C DO 100 I=1,14
180 C READ(13,50) (D(I,J), J=1,8)
190 C CONTINUE
200 C
210 C THIS SECTION SETS THE DO LCOPS AND ADVANCES THE LOAD FACTOR, MINIMUM
220 C FREQUENCY, PASSENGER FLOW AND STAGE LENGTH PARAMETERS ACCORDING TO
230 C SPECIFICATIONS IN THE DATA DECK
240 C I1=D(1,1)
250 C DO 402 J=1,I1
260 C JO=J
270 C JO=JO+1
280 C I2=D(5,1)
290 C DO 403 K=1,I2
300 C KO=K
310 C KO=KO+1
320 C CAP=D(3,2)
330 C I3=D(3,1)
340 C DO 404 I=1,I3
350 C SL=D(4,2)
360 C I4=D(4,1)
370 C DO 405 M=1,I4
380 C I13=D(13,1)
390 C DO 407 N=1,I13
400 C NO=N
410 C NO=NO+1
420 C
430 C CALCULATE ROUND TRIP TRAVEL TIME
440 C TT=2*(SL/D(10,1))+0.667
450 C
460 C CALCULATE TWO WAY PASSENGER FLOW DURING THE PEAK PERIOD
470 C BPHP=CAP*D(7,1)-D(12,1)*2
480 C
490 C CALCULATE UNIDIRECTIONAL FLOW DURING PEAK PERIOD
500 C UPHP=BPHP/2.0
510 C
520 C CALCULATE TWO WAY PASSENGER FLOW DURING THE BASE PERIOD
530 C BPP=CAP-BPHP
540 C
550 C CALCULATE UNIDIRECTIONAL PASSENGER FLOW DURING BASE PERIOD
560 C UBPP=BPP/2.0
570 C
580 C CALCULATE UNIDIRECTIONAL MINIMUM ALLOWABLE FREQUENCY
590 C FOR THE PEAK PERIOD
600 C PFR=D(5,KO)/2.0
610 C
620 C THIS SECTION CALCULATES TOTAL PEAK PERIOD USABLE SEATS FOR A TILT-
630 C ROTOR AIRCRAFT OPERATING AT THE PEAK PERIOD MINIMUM ALLOWABLE
640 C FREQUENCY
650 C PCAP=D(9,1)+D(5,KO)*D(1,JO)
660 C IF (BPHP-PCAP)190,190,192
670 C
680 C IN THIS SECTION THE PROGRAM SETS ITS OWN PEAK PERIOD FREQUENCY
690 C IF THE MINIMUM FREQUENCY DOES NOT SATISFY THE DEMAND
700 C PFR=UPHP/(D(9,1)+D(1,JO))
710 C PFR=PFR+.99
720 C IPFR=IFIX(PFR)
730 C PFR=IPFR
740 C
750 C THIS SECTION CALCULATES THE NUMBER OF INDIVIDUAL AIRCRAFT
760 C MOVEMENTS AND NUMBER OF USABLE SEATS DURING THE PEAK PERIOD
770 C UPCAP=PFR*D(9,1)+D(1,JO)
780 C UAR=PFR
790 C AR=UAR*2.0
800 C PCAP=UPCAP*2.0
810 C
820 C CALCULATE UNIDIRECTIONAL MINIMUM ALLOWABLE FREQUENCY FOR
830 C THE BASE PERIOD
840 C OFR=D(5,KO)/2.0
850 C
860 C
870 C
880 C
890 C
900 C
910 C
920 C
930 C
940 C
950 C
960 C
970 C
980 C
990 C
995 C

```



# LINKTR

```

1000 C THIS SECTION CALCULATES TOTAL BASE PERIOD USABLE SEATS FOR A TILT-
1010 C ROTOR AIRCRAFT OPERATING AT THE BASE PERIOD MINIMUM ALLOWABLE
1020 C FREQUENCY
1030 C  $OCAP = D(9,1) * D(4,KU) * D(2,JC)$ 
1040 C  $IF (BPP - OCAP) 39C,390,392$ 
1050 C
1060 C IN THIS SECTION THE PROGRAM SETS ITS OWN BASE PERIOD FREQUENCY IF
1070 C MINIMUM FREQUENCY DOES NOT SATISFY THE DEMAND
1080 392  $OFR = UBPP / (D(9,1) * D(2,JO))$ 
1090  $OFR = OFR + 0.99$ 
1100  $IOFR = IFIX(OFR)$ 
1110  $OFR = IOFR$ 
1120 C
1130 C THIS SECTION CALCULATES THE NUMBER OF INDIVIDUAL AIRCRAFT MOVEMENTS
1140 C AND NUMBER OF USABLE SEATS DURING THE BASE PERIOD
1150 390  $UOCAP = OFR * D(9,1) * D(2,JO)$ 
1160  $UOAR = OFR$ 
1170  $OAR = UOAR * 2.0$ 
1180  $OCAP = UOCAP * 2.$ 
1190 C
1200 C
1210 C
1220 C
1230 C
1240 C CALCULATE TOTAL DAILY UNIDIRECTIONAL FREQUENCY
1250  $UTFREQ = CFR + PFR$ 
1260 C
1270 C CALCULATE DAILY TWO WAY PEAK PERIOD FREQUENCY
1280  $DPFR = PFR * 2.0$ 
1290 C
1300 C CALCULATE DAILY TWO WAY BASE PERIOD FREQUENCY
1310  $DOFR = OFR * 2.0$ 
1320 C
1330 C CALCULATE DAILY TWO WAY TOTAL FREQUENCY
1340  $DFREQ = DPFR + DOFR$ 
1350 C
1360 C CALCULATE THE NUMBER OF PASSENGERS IN EACH PEAK HOUR
1370  $PHP = CAP * D(7,1)$ 
1380 C
1390 C CALCULATE NUMBER OF ANNUAL PASSENGERS
1400  $BNSP = CAP * 365$ 
1410 C
1420 C CALCULATE TOTAL ANNUAL MILES
1430  $TAM = SL * DFREQ * 365$ 
1440 C
1450 C CALCULATE ANNUAL FLIGHT HOURS
1460  $AFH = (TT / 2.) * DFREQ * 365.$ 
1470 C
1480 C CALCULATE PEAK PERIOD HEADWAY
1490  $PHD = (2 * D(12,1)) / PFR$ 
1500 C
1510 C CALCULATE BASE PERIOD HEADWAY
1520  $OHND = (D(11,1) - (2 * C(12,1))) / OFR$ 
1530 C
1540 C THIS SECTION CALCULATES THE NUMBER OF VTOL AIRCRAFT
1550 C NEEDED TO OPERATE SERVICE
1560  $IF (D(12,1) - (TT / 2.)) 151,15C,150$ 
1570 150  $BNTR = (TT / (2 * PHD)) + 1.$ 
1580  $GO TO 152$ 
1590 151  $BNTR = (D(12,1) * ((CHD / PHD - 1) / OHND) + (TT / (2 * OHND))) + 1$ 
1600 152  $NTR = IFIX(BNTR)$ 
1610  $BNTR = NTR * 2.$ 
1620  $BNTR = BNTR + 0.99$ 
1630  $BNTR = IFIX(BNTR)$ 
1640 C
1650 C THIS SECTION CALCULATES DIRECT OPERATING COSTS
1660  $ACTI = 0.12448 * 9000000. * BNTR$ 
1670  $HI = 0.02 * 0.80 * 9000000. * BNTR$ 
1680  $FC = 240. * AFH$ 
1690  $FO = ((277. * (8.63 * SL)) / 6.5) * 0.95 * DFREQ * 365.$ 
1700  $DM = 259. * 15 * SL * DFREQ$ 
1710  $AMB = 0.60 * DM$ 
1720  $TDOC = ACTI + HI + FC + FO + DM + AMB$ 
1730 C
1740 C THIS SECTION CALCULATES TOTAL INDIRECT OPERATING COST
1750 C
1760 C
1770 C
1780 C
1790 C
1800 C THIS SECTION CALCULATES ANNUAL TERMINAL COST FOR EACH TERMINAL
1810  $FDI = 0.15113 * 4027500.$ 
1820  $FDM = 6334.$ 
1830  $GA = 0.15113 * 45315C.$ 
1840  $GAM = 997.$ 

```

LINKIR

80

## LINKTR

```

2300 WRITE(20,3)
2301 WRITE(20,27) TAAC
2302 WRITE(20,4)
2303 WRITE(20,29) PPCUU
2304 WRITE(20,17)
2305 WRITE(20,3)
2306 WRITE(20,38) PPUUV
2307 WRITE(20,18)
2308 WRITE(20,20)
2309 WRITE(20,8)
2310 WRITE(20,39) PPWCV
2311 WRITE(20,19)
2312 WRITE(20,8)
2313 WRITE(20,61) BNTR
2314 WRITE(20,4)
2315 WRITE(20,62) TERCOS
2316 C
2317 PLACE OPTION OUTPUT PRINT AND FORMAT STATEMENTS HERE
2318 NO=NO-1
2319
2320 407 CONTINUE
2321 SL=SL+D(4,3)
2322 405 CONTINUE
2323 CAP=CAP+D(3,3)
2324 404 CONTINUE
2325 KO=KO-1
2326 403 CONTINUE
2327 JO=JO-1
2328 402 CONTINUE
2329 STOP
2330 FORMAT(1H0)
2331 8 FORMAT(1H0,15X,"ONE WAY STAGE LENGTH",15X,F7.1,2X,"MILES")
2332 10 FORMAT(1H0,15X,"DAILY PASSENGER FLOW ON LINK",7X,F7.1)
2333 11 FORMAT(1H0,51X,"PEAK",11X,"BASE")
2334 12 FORMAT(1H0,5X,"ALL VALUES FOR THE PEAK PERIOD ARE THE COMBINED")
2335 13 FORMAT(1H0,5X,"TOTAL OF THE MORNING AND EVENING PEAKS")
2336 14 FORMAT(1H0,5X,"ALL OF THE ABOVE VALUES REPRESENT A TWO WAY FLOW")
2337 15 FORMAT(1H0,5X,"ON THE LINK")
2338 16 FORMAT(1H0,5X,"DURATION OF PERIOD, HOURS",19X,F7.1,2X,F7.1)
2339 31 FORMAT(1H0,5X,"LOAD FACTOR",33X,F7.1,8X,F7.1)
2340 32 FORMAT(1H0,5X,"USABLE SEATS PER TOTAL PERIOD",15X,F7.1,8X,F7.1)
2341 33 FORMAT(1H0,5X,"PASSENGER FLOW DURING PERIOD",16X,F7.1,8X,F7.1)
2342 34 FORMAT(1H0,5X,"MINIMUM ALLOWABLE FREQUENCY",17X,F7.1,8X,F7.1)
2343 35 FORMAT(1H0,5X,"ACTUAL FREQUENCY PER PERIOD",17X,F7.1,2X,F7.1)
2344 25 FORMAT(1H0,5X,"ANNUAL DIRECT COST",13X,F15.2)
2345 26 FORMAT(1H0,5X,"ANNUAL INDIRECT COST",11X,F15.2)
2346 27 FORMAT(1H0,5X,"ANNUAL TOTAL COST",14X,F15.2)
2347 28 FORMAT(1H0,5X,"CCST PER PASSENGER MILE",9X,F13.4)
2348 29 FORMAT(1H0,5X,"TOTAL COST")
2349 36 FORMAT(1H0,5X,"CCST PER PASSENGER MILE",9X,F13.4)
2350 38 FORMAT(1H0,5X,"TOTAL COST MINUS CAPITAL COST")
2351 18 FORMAT(1H0,5X,"NET INCLUDING VEHICLES")
2352 20 FORMAT(1H0,5X,"CCST PER PASSENGER MILE",9X,F13.4)
2353 39 FORMAT(1H0,5X,"TOTAL COST MINUS CAPITAL COST")
2354 19 FORMAT(1H0,31X,"TILTRATOR")
2355 41 FORMAT(1H0,2)
2356 50 FORMAT(1H0,5X,"FLEET SIZE",14X,F5.2)
2357 61 FORMAT(1H0,5X,"TERMINAL CCST",1X,F15.2)
2358 62
2359 END
2360

```

## Computer Program Input

The data file used with the LINKTR program is called VTOL and consists of an array of 14 rows and 8 columns (8 F 10.2 format), which is referred to as array D (I,J). The following entries are made from each row.

Row 1 and 2: These lines specify the base period and peak period load factors to be used in the analysis. At least one pair of load factors must be specified, but the program can analyze up to 7 pairs of load factors.

Note: Any columns not being used to specify load factors may be left blank.

Row 3: This row specifies the daily two-way passenger flow on the link. It is assumed that passenger flows are equal in both directions on the link.

Row 4: This row specifies the one-way, air statute mile stage length on the link. This data card corresponds in format to Row 3.

Row 5 and 6: These rows specify the frequency, called here minimum allowable frequency, on which vehicles will operate in the peak and base periods. Like Rows 1 and 2, these rows operate as a pair. Row 5 specifies the peak period minimum allowable frequency, Row 6 specifies the base period minimum allowable frequency. Minimum allowable frequency is defined as that number of departures, in both directions on the link, which must be performed, to conform to some standard or level of service. At least one pair of frequencies must be given, but up to seven pairs of frequencies can be read by the program.

Row 7: Row 7 specifies the fraction of daily passengers on the link in each peak hour. For example, if there are 2000 daily passengers, and in each peak hour there are 200 passengers on the link, then the fraction of daily passengers on the link in each peak hour is  $1/10$ , or .10.

Row 8: Does not apply to air programs. Enter a 1.0 in the first 10 columns.

Row 9: Row 9 specifies the aircraft capacity; the number of seats in one vehicle.

Row 10: This row specifies the average cruising speed of the aircraft. The speed is given in miles per hour.

Row 11: Row 11 specifies the number of hours in a 24 hour day the system is in operation. Time starts when the first vehicle departs and ends when the last vehicle departs.

Row 12: Row 12 specifies the number of hours in each peak period. The morning and evening peaks are assumed to have the same duration. This row shows the number of hours out of the total hours of operation that are in each peak period.

Row 13 and 14: Rows 13 and 14 specify the number of intermediate plus endpoint stops on the link. At least one pair of terminal combinations must be specified, but the program will analyze up to seven combinations; at least the two endpoints must be specified.

#### Computer Program Output

The computer output calculated by the LINKTR program, is listed under the heading "STANDARD", which gives annual cost and cost per passenger mile for capacities 500-3000 daily passengers (in 500 passenger increments) and for stage lengths 100-300 miles (in 100 mile increments).

VTOL			
100	1.0		
110	9:0	0:5	
130	1:0	500:0	500:00
140	0:1	8:0	
150	1:0	12:00	
160	4:0		
170	2:0		
180	1:0		
190	2:0		
200	1:0		
210	2:0		
220	1:0		
230		2:0	

STANDARD	ONE WAY STAGE LENGTH DAILY PASSENGER FLOW ON LINK	TILTROTOR	100.0 500.0	MILES	PEAK	BASE
1	0					
2	0					
3	0					
4	0					
5	0					
6	0					
7	0					
8	0					
9	0					
10	0					
11	0					
12	0					
13	0					
14	0					
15	0					
16	0					
17	0					
18	0					
19	0					
20	0					
21	0					
22	0					
23	0					
24	0					
25	0					
26	0					
27	0					
28	0					
29	0					
30	0					
31	0					
32	0					
33	0					
34	0					
35	0					
36	0					
37	0					
38	0					
39	0					
40	0					
41	0					
42	0					
43	0					
44	0					
45	0					
46	0					
		DURATION OF PERIOD, HOURS				
		LOAD FACTOR				
		USABLE SEATS PER TOTAL PERIOD				
		PASSENGER FLOW DURING PERIOD				
		MINIMUM ALLOWABLE FREQUENCY				
		ACTUAL FREQUENCY PER PERIOD				
		ALL OF THE ABOVE VALUES REPRESENT A TWO WAY FLOW ON THE LINK				
		ALL VALUES FOR THE PEAK PERIOD ARE THE COMBINED TOTAL OF THE MORNING AND EVENING PEAKS				
		ANNUAL DIRECT COST				
		ANNUAL INDIRECT COST				
		ANNUAL TOTAL COST				
		COST PER PASSENGER MILE TOTAL COST				
		COST PER PASSENGER MILE TOTAL COST MINUS CAPITAL COST NOT INCLUDING VEHICLES				
		COST PER PASSENGER MILE TOTAL COST MINUS CAPITAL COST				
		FLEET SIZE				
		TERMINAL COST				

## APPENDIX B

### CTOL Cost Computer Program

This program, named "LINKDC9," is the computerized version of the CTOL cost model. This program computes the same output that was calculated by the VTOL cost model and follows the same basic logic as outlined in Appendix A for the LINKTR program. A sample of the computer output for the program is listed under the heading "STANDARD." The data file is called CTOL and has the same format and entries that the VTOL file has.



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LINKDC9

```

100 C INTERCITY PASSENGER MODES COST COMPARISON
110 C LOST CF McDONNELL DOUGLAS DC-9-30 OPERATING FROM EXISTING TERMINALS FOR
120 C A SINGLE LINK
130 C
140 C DIMENSION D(14,8)
150 C
160 C THIS SECTION READS THE DATA MATRIX INTO THE PROGRAM
170 C DO 100 J=1,14
180 C READ(13,50) (D(I,J),J=1,8)
190 C CONTINUE
200 C
210 C THIS SECTION SETS THE DO LOOPS AND ADVANCES THE LOAD FACTOR, MINIMUM
220 C FREQUENCY, PASSENGER FLOW AND STAGE LENGTH PARAMETERS ACCORDING TO
230 C SPECIFICATIONS IN THE DATA DECK
240 C I1=D(1,1)
250 C DO 402 J=1,I1
260 C J0=J
270 C J0=J0+1
280 C I2=D(5,1)
290 C DO 403 K=1,I2
300 C K0=K
310 C K0=K0+1
320 C CAP=D(3,2)
330 C I3=D(3,1)
340 C DO 404 I=1,I3
350 C SL=D(4,2)
360 C I4=D(4,1)
370 C DO 405 M=1,I4
380 C I13=D(13,1)
390 C DO 407 N=1,I13
400 C N0=N
410 C N0=N0+1
420 C
430 C
440 C CALCULATE ROUND TRIP TRAVEL TIME
450 C TT=2*(SL/D(10,1))+0.667
460 C
470 C CALCULATE TWO WAY PASSENGER FLOW DURING THE PEAK PERIOD
480 C BPHP=CAP*D(7,1)*D(12,1)*2
490 C
500 C CALCULATE UNIDIRECTIONAL FLOW DURING PEAK PERIOD
510 C UPHP=BPHP/2.0
520 C
530 C CALCULATE TWO WAY PASSENGER FLOW DURING THE BASE PERIOD
540 C BPP=CAP-BPHP
550 C
560 C CALCULATE UNIDIRECTIONAL PASSENGER FLOW DURING BASE PERIOD
570 C UBPP=BPP/2.0
580 C
590 C CALCULATE UNIDIRECTIONAL MINIMUM ALLOWABLE FREQUENCY
600 C FOR THE PEAK PERIOD
610 C PFR=D(5,K0)/2.0
620 C
630 C THIS SECTION CALCULATES TOTAL PEAK PERIOD USABLE SEATS FOR A CTOL
640 C AIRCRAFT OPERATING AT THE PEAK PERIOD MINIMUM ALLOWABLE
650 C FREQUENCY
660 C PCAP=D(9,1)*D(5,K0)*D(1,J0)
670 C IF (BPHP-PCAP)140,190,192
680 C
690 C IN THIS SECTION THE PROGRAM SETS ITS OWN PEAK PERIOD FREQUENCY
700 C IF THE MINIMUM FREQUENCY DOES NOT SATISFY THE DEMAND
710 C PFR=UPHP/(D(9,1)*D(1,J0))
720 C PFR=PFR*0.99
730 C IPFR=IFIX(PFR)
740 C PFR=IPFR
750 C
760 C THIS SECTION CALCULATES THE NUMBER OF INDIVIDUAL AIRCRAFT
770 C MOVEMENTS AND NUMBER OF USABLE SEATS DURING THE PEAK PERIOD
780 C UPCAP=PFR*D(9,1)*D(1,J0)
790 C UAR=PFR
800 C AR=UAR*2.0
810 C PCAP=UPCAP*2.0
820 C
830 C CALCULATE UNIDIRECTIONAL MINIMUM ALLOWABLE FREQUENCY FOR
840 C THE BASE PERIOD
850 C OFR=D(6,K0)/2.0
860 C

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LINKDC9
1000 C THIS SECTION CALCULATES TOTAL BASE PERIOD USABLE SEATS FOR A CTOL
1010 C AIRCRAFT OPERATING AT THE BASE PERIOD MINIMUM ALLOWABLE
1020 C FREQUENCY
1030 C  $OCAP = D(9,1) * D(6,KO) * D(2,JC)$ 
1040 C IF  $(6PP - OCAP) \geq 0$ , 390, 392
1050 C
1060 C IN THIS SECTION THE PROGRAM SETS ITS OWN BASE PERIOD FREQUENCY IF
1070 C MINIMUM FREQUENCY DOES NOT SATISFY THE DEMAND
1080 C  $OFR = UPP / (D(9,1) * D(2,JO))$ 
1090 C  $OFR = OFR + 0.99$ 
1100 C  $IOFR = IFIX(OFR)$ 
1110 C  $OFR = IOFR$ 
1120 C
1130 C THIS SECTION CALCULATES THE NUMBER OF INDIVIDUAL AIRCRAFT MOVEMENTS
1140 C AND NUMBER OF USABLE SEATS DURING THE BASE PERIOD
1150 C  $UOCAP = OFR * D(9,1) * D(2,JO)$ 
1160 C  $UOAR = OFR$ 
1170 C  $OAR = UOAR * 2.0$ 
1180 C  $OCAP = UOCAP * 2.$ 
1190 C
1200 C
1210 C
1220 C
1230 C
1240 C CALCULATE TOTAL DAILY UNIDIRECTIONAL FREQUENCY
1250 C  $UTFREQ = OFR + PFR$ 
1260 C
1270 C CALCULATE DAILY TWO WAY PEAK PERIOD FREQUENCY
1280 C  $DPFR = PFR * 2.0$ 
1290 C
1300 C CALCULATE DAILY TWO WAY BASE PERIOD FREQUENCY
1310 C  $DOFR = OFR * 2.0$ 
1320 C
1330 C CALCULATE DAILY TWO WAY TOTAL FREQUENCY
1340 C  $DFREQ = DPFR + DOFR$ 
1350 C
1360 C CALCULATE THE NUMBER OF PASSENGERS IN EACH PEAK HOUR
1370 C  $PHP = CAP * D(7,1)$ 
1380 C
1390 C CALCULATE NUMBER OF ANNUAL PASSENGERS
1400 C  $BNSP = CAP * 365$ 
1410 C
1420 C CALCULATE TOTAL ANNUAL MILES
1430 C  $TAM = SL * DFREQ * 365$ 
1440 C
1450 C CALCULATE ANNUAL FLIGHT HOURS
1460 C  $AFH = (SL / D(10,1)) * DFREQ * 365.$ 
1470 C
1480 C CALCULATE PEAK PERIOD HEADWAY
1490 C  $PHD = (2 * D(12,1)) / PFR$ 
1500 C
1510 C CALCULATE BASE PERIOD HEADWAY
1520 C  $OMD = (D(11,1) - (2 * D(12,1))) / OFR$ 
1530 C
1540 C THIS SECTION CALCULATES THE NUMBER OF CTOL AIRCRAFT
1550 C NEEDED TO OPERATE SERVICE
1560 C IF  $(D(12,1) - (TT / 2)) \geq 0$ , 151, 152, 150
1570 C  $BNTR = (TT / (2 * PHD)) + 1.$ 
1580 C GO TO 152
1590 C  $BNTR = (D(12,1) - ((OMD / PHD - 1) / OMD) * (TT / (2 * OMD))) + 1$ 
1600 C  $NTR = IFIX(BNTR)$ 
1610 C  $BNTR = NTR * 2.$ 
1620 C  $BNTR = BNTR + 0.99$ 
1630 C  $BNTR = IFIX(BNTR)$ 
1640 C
1650 C THIS SECTION CALCULATES DIRECT OPERATING COSTS
1660 C  $ACTI = 0.18448 * 12842000. * BNTR$ 
1670 C  $HI = 0.02 * 0.90909 * 12842000. * BNTR$ 
1680 C  $FC = 290.51 * AFH$ 
1690 C  $FO = 799.35 * AFH$ 
1700 C  $DM = 124.21 * AFH$ 
1710 C  $AMB = 0.60 * DM$ 
1720 C  $TDOC = ACTI + HI + FC + FO + DM + AMB$ 
1730 C
1740 C THIS SECTION CALCULATES TOTAL INDIRECT OPERATING COST
1750 C
1760 C
1770 C THIS SECTION CALCULATES ANNUAL CONVENTIONAL AIR TERMINAL COST
1780 C  $TERCA = 27.70 * 365. * CAP$ 
1790 C
1800 C THIS SECTION CALCULATES AIRCRAFT PARKING COST
1810 C  $APRKM = 14715. * 0.026 * BNTR$ 
1820 C
1830 C
1840 C
1850 C
1860 C
1870 C
1880 C
1890 C
1900 C
1910 C
1920 C
1930 C

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LINKDC9
1910 C THIS SECTION CALCULATES COST OF CENTRAL OFFICE BUILDING
1911 PERC=25000.0*CAP
1912
1913 C THIS SECTION CALCULATES MISCELLANEOUS COSTS
1914 CMISC=47.74*0.7*10*TAM
1915 TIOC=TERCA+APRKM+PERC+CMISC
1916
1917 C THIS SECTION COMPUTES THE INFORMATION TO BE PRINTED AS OUTPUT
1918
1919 C THIS SECTION CALCULATES TOTAL COST
1920 TAAC=TDOC+TIOC
1921
1922 C THIS SECTION CALCULATES TOTAL OPERATING COST LESS ALL COST
1923 TALCAV=TAAC-ACTI
1924
1925 UUVHGV=TDOC-ACTI
1926
1927 ZZ=CAP+SL*365
1928 PPCUU=TAAC/ZZ
1929 PPWGV=TALCAV/ZZ
1930
1931 PH=D(12,1)*2
1932 DP=D(11,1)-PH
1933
1934 C THIS SECTION PRINTS THE OUTPUT
1935 WRITE(20,6)
1936 WRITE(20,8)
1937 WRITE(20,41)
1938 WRITE(20,8)
1939 WRITE(20,10) SL
1940 WRITE(20,11) CAP
1941 WRITE(20,8)
1942 WRITE(20,8)
1943 WRITE(20,8)
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1945 WRITE(20,12)
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LINKDC9

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2620 10 FORMAT(1H0,15X,"ONE WAY STAGE LENGTH",15X,F7.1,2X,"MILES")
2630 11 FORMAT(1H0,15X,"DAILY PASSENGER FLOW ON LINK",7X,F7.1)
2640 12 FORMAT(1H0,51X,"PEAK",11X,"BASE")
2650 13 FORMAT(1H0,5X,"ALL VALUES FOR THE PEAK PERIOD ARE THE COMBINED")
2660 14 FORMAT(1H0,5X,"TOTAL OF THE MORNING AND EVENING PEAKS")
2670 15 FORMAT(1H0,5X,"ALL OF THE ABOVE VALUES REPRESENT A TWO WAY FLOW")
2680 16 FORMAT(1H0,5X,"ON THE LINK")
2690 31 FORMAT(1H0,5X,"DURATION OF PERIOD, HOURS",19X,F7.1,8X,F7.1)
2700 32 FORMAT(1H0,5X,"LOAD FACTOR",33X,F7.1,8X,F7.1)
2710 33 FORMAT(1H0,5X,"USABLE SEATS PER TOTAL PERIOD",15X,F7.1,8X,F7.1)
2720 34 FORMAT(1H0,5X,"PASSENGER FLOW DURING PERIOD",16X,F7.1,3X,F7.1)
2730 35 FORMAT(1H0,5X,"MINIMUM ALLOWABLE FREQUENCY",17X,F7.1,8X,F7.1)
2740 37 FORMAT(1H0,5X,"ACTUAL FREQUENCY PER PERIOD",17X,F7.1,8X,F7.1)
2750 38 FORMAT(1H0,5X,"ANNUAL DIRECT COST",13X,F15.2)
2760 25 FORMAT(1H0,5X,"ANNUAL INDIRECT COST",11X,F15.2)
2770 26 FORMAT(1H0,5X,"ANNUAL TOTAL COST",14X,F15.2)
2780 27 FORMAT(1H0,5X,"CCST PER PASSENGER MILE",9X,F13.4)
2790 29 FORMAT(1H0,5X,"TOTAL COST")
2800 17 FORMAT(1H0,5X,"CCST PER PASSENGER MILE",9X,F13.4)
2810 39 FORMAT(1H0,5X,"TOTAL COST MINUS VEHICLE COST")
2820 19 FORMAT(1H0,31X,"CTOL DC-9-30")
2830 41 FORMAT(8F10.2)
2840 50 FORMAT(1H0,5X,"FLEET SIZE",14X,F4.1)
2850 60 FORMAT(1H0,5X,"TERMINAL CCST",1X,F15.2)
2860 61
2870 END

```



[illegible]

ONE WAY STAGE LENGTH  
DAILY PASSENGER FLOW

100:0  
500:0  
MILES

PEAK	BASE
4.0	12.0
7.8	5
736.0	690.0
200.0	300.0
8.0	12.0
8.0	12.0

DURATION OF PERIOD, HOURS

4.800.000  
736.000  
200.000  
88.000

USABLE SEATS PER TOTAL PERIOD	PASSENGER FLOW DURING PERIOD	MINIMUM ALLOWABLE FREQUENCY	ACTUAL FREQUENCY PER PERIOD
100	100	100	100
90	90	90	90
80	80	80	80
70	70	70	70
60	60	60	60
50	50	50	50
40	40	40	40
30	30	30	30
20	20	20	20
10	10	10	10
0	0	0	0

ALL OF THE ABOVE VALUES REPRESENT A TWO WAY FLOW  
ON THE LINK

ALL VALUES FOR THE PEAK PERIOD ARE THE COMBINED TOTAL OF THE MORNING AND EVENING PEAKS

ANNUAL DIRECT COST	8099550.31
ANNUAL INDIRECT COST	5737089.69
ANNUAL TOTAL COST	13836640.00
COST PER PASSENGER MILE TOTAL COST	.7582
COST PER PASSENGER MILE TOTAL COST MINUS VEHICLE COST	.4985
FLEET SIZE	2.0
TERMINAL COST	5055250.00

## APPENDIX C

### High Speed Rail Cost Computer Program

This program is the computerized version of the HSR cost model and was given the name "LINKML." For every stage length, passenger flow, minimum allowable frequency and maximum load factor specified in the data entries, the following calculations are performed and printed in the computer output:

- usable seats for both peak and base periods
- actual train frequency per period (number of daily departures in each period)
- annual fixed cost (dollars)
- annual variable cost (dollars)
- annual total cost (dollars)
- cost per passenger mile based on total cost
- cost per passenger mile based on variable cost
- cost per passenger mile based on variable cost minus vehicle cost

\* Note: Distances refer to airline distances

The basic logic of the LINKML program is outlined in the following steps:

1. Read data
2. Calculate passenger flows during the peak and base periods
3. Calculate train consists for a train of maximum length
4. Calculate usable seats for a train of maximum length operating at the peak period - minimum allowable frequency
5. Test whether usable seats generated from running at minimum allowable frequency satisfies peak demand
  - If demand is satisfied, go to step 6
  - If demand is not satisfied, increase frequency in order to satisfy demand; go to step 6

6. Calculate the number of individual car movements and number of usable seats during the peak period
7. Repeat steps 2 and 4 through 6 for base period
8. Determine the number of locomotives and cars required to provide the service specified above
9. Calculate fixed, variable, and total costs.
10. Calculate costs per passenger miles
11. Print output

\* DO LOOPS repeat above process for all stage lengths and capacities.

In addition to performing the calculations for the base case as described in the development of the HSR cost model, the application of the program was particularly useful in performing a sensitivity analysis of various parameters used in the model. The following parameters were changed and their effect on annual cost and cost per passenger mile were observed: train frequency, fuel cost, interest rates, load factors, track upgrading cost, and vehicle cost.



```

LINKML
100 C INTERCITY PASSENGER MODES COST COMPARISON
110 C COST OF METROLINER OPERATING FROM EXISTING TERMINALS FOR
120 C A SINGLE LINK
130 C
140 C DIMENSION D(14,2)
150 C
160 C THIS SECTION READS THE DATA MATRIX INTO THE PROGRAM
170 C DO 201 J=1,14
180 C READ(14,50) (D(I,J), J=1,2)
190 C CONTINUE
200 C
210 C THIS SECTION SETS THE DO LOOPS AND ADVANCES THE LOAD FACTOR, MINIMUM
220 C FREQUENCY, PASSENGER FLOW AND STAGE LENGTH PARAMETERS ACCORDING TO
230 C SPECIFICATIONS IN THE DATA DECK
240 C I1=D(1,1)
250 C DO 402 J=1,I1
260 C J0=J
270 C J0=J0+1
280 C I2=D(5,1)
290 C DO 403 K=1,I2
300 C K0=K
310 C K0=K0+1
320 C CAP=D(3,2)
330 C I3=D(3,1)
340 C DO 404 I=1,I3
350 C SL=D(4,2)
360 C I4=D(4,1)
370 C DO 405 F=1,I4
380 C I13=D(13,1)
390 C DO 407 N=1,I13
400 C NO=N
410 C NO=NO+1
420 C
430 C ZSL=SL
440 C SL=SL*1.14
450 C BI=D(13,NO)+D(14,NO)
460 C BBI=BI-2.
470 C TIS=BBI*.0833
480 C
490 C CALCULATE ROUND TRIP TRAVEL TIME
500 C TT=2*((SL/100.)+TIS)+2.
510 C
520 C CALCULATE TWO WAY PASSENGER FLOW DURING THE PEAK PERIOD
530 C BPMP=CAP*D(7,1)+D(12,1)*2
540 C
550 C CALCULATE UNIDIRECTIONAL FLOW DURING PEAK PERIOD
560 C UPHP=BPMP/2.0
570 C
580 C CALCULATE TWO WAY PASSENGER FLOW DURING THE BASE PERIOD
590 C BPP=CAP-BPMP
600 C
610 C CALCULATE UNIDIRECTIONAL PASSENGER FLOW DURING BASE PERIOD
620 C UBPP=BPP/2.0
630 C
640 C CALCULATE UNIDIRECTIONAL MINIMUM ALLOWABLE FREQUENCY
650 C FOR THE PEAK PERIOD
660 C PFR=D(5,K0)/2.0
670 C
680 C THIS SECTION CALCULATES TRAIN CONSIST FOR A TRAIN OF
690 C MAXIMUM LENGTH
700 C CAR=D(8,1)/2.0
710 C NCAR=IFIX(CAR)
720 C KCAR=CAR+.5
730 C SCAR=IFIX(KCAR)
740 C
750 C CALCULATE THE CAPACITY OF A TRAIN OF MAXIMUM LENGTH
760 C TMAX=(D(9,1)*NCAR)+ (D(9,2)*SCAR)
770 C
780 C THIS SECTION CALCULATES TOTAL PEAK PERIOD USABLE SEATS FOR TRAIN OF
790 C MAXIMUM LENGTH OPERATING AT THE PEAK PERIOD MINIMUM ALLOWABLE
800 C FREQUENCY
810 C TMDP=TMAX*D(5,K0)+D(1,J0)
820 C ITMDP=IFIX(TMDP)
830 C TMDP=ITMDP
840 C IF (BPMP-TMDP)190,190,192
850 C
860 C IN THIS SECTION THE PROGRAM SETS ITS OWN PEAK PERIOD FREQUENCY
870 C IF THE MINIMUM FREQUENCY DOES NOT SATISFY THE DEMAND

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LINKML
785 192 PFR=UPHP/(TMAX*D(1,J0))
790 PFR=PFR+0.99
800 IPFR=IFIX(PFR)
810 PFR=IPFR
815 C
820 C THIS SECTION CALCULATES THE NUMBER OF INDIVIDUAL CAR MOVEMENTS
830 C AND NUMBER OF USEABLE SEATS DURING THE PEAK PERIOD
840 190 UPCAP=PFR*D(9,2)*D(1,J0)
850 UCT=1.0
860 195 IF(UPHP-UPCAP) 121,181,196
870 196 UCT=UCT+1.0
880 UPCAP=UPCAP+(PFR*D(9,1)+D(1,J0))
890 IF(UPHP-UPCAP) 121,181,196
900 198 UCT=UCT+1.0
910 UPCAP=UPCAP+(PFR*D(9,2)+D(1,J0))
920 GO TO 195
960 181 PCAP=UPCAP*2
965 C
970 C CALCULATE UNIDIRECTIONAL MINIMUM ALLOWABLE FREQUENCY FOR
980 C THE BASE PERIOD
990 OFR=D(6,K0)/2.0
995 C
1000 C THIS SECTION CALCULATES TOTAL BASE PERIOD USABLE SEATS FOR TRAIN
1010 C OF MAXIMUM LENGTH OPERATING AT THE BASE PERIOD MINIMUM ALLOWABLE
1020 C FREQUENCY
1030 TMD0=TMAX*D(6,K0)*D(2,J0)
1040 ITMD0=IFIX(TMD0)
1045 TMD0=ITMD0
1050 IF(BPP-TMD0) 390,390,392
1055 C
1060 C IN THIS SECTION THE PROGRAM SETS ITS OWN BASE PERIOD FREQUENCY IF
1070 C MINIMUM FREQUENCY DOES NOT SATISFY THE DEMAND
1080 392 OFR=UBPP/(TMAX*D(2,J0))
1090 OFR=OFR+0.99
1095 IOFR=IFIX(OFR)
1100 OFR=IOFR
1105 C
1110 C THIS SECTION CALCULATES THE NUMBER OF INDIVIDUAL CAR MOVEMENTS
1120 C AND NUMBER OF USABLE SEATS DURING THE BASE PERIOD
1130 390 UOCAP=OFR*D(9,2)*D(2,J0)
1140 UOCT=1.0
1150 295 IF(UBPP-UOCAP) 221,281,296
1160 296 UOCT=UOCT+1.0
1170 UOCAP=UOCAP+(OFR*(D(9,1)+D(2,J0)))
1171 IF(UBPP-UOCAP) 221,281,296
1172 298 UOCT=UOCT+1.0
1173 UOCAP=UOCAP+(OFR*(D(9,2)+D(2,J0)))
1175 GO TO 295
1210 281 OCAP=UOCAP*2.0
1215 C
1220 C CALCULATE DAILY UNIDIRECTIONAL TOTAL CAR MOVEMENTS
1230 UTC=(UCT*PFR)+(UOCT*OFR)
1231 C
1232 C CALCULATE DAILY TWO WAY TOTAL CAR MOVEMENTS
1233 BUTC=2.*UTC
1235 C
1240 C CALCULATE TOTAL DAILY UNIDIRECTIONAL FREQUENCY
1250 UTFREQ=OFR+PFR
1255 C
1260 C CALCULATE DAILY TWO WAY PEAK PERIOD FREQUENCY
1270 DPFR=PFR*2.0
1275 C
1280 C CALCULATE DAILY TWO WAY BASE PERIOD FREQUENCY
1290 DOFR=OFR*2.0
1295 C
1300 C CALCULATE DAILY TWO WAY TOTAL FREQUENCY
1310 DFREQ=DPFR+DOFR
1315 C
1320 C CALCULATE THE NUMBER OF PASSENGERS IN EACH PEAK HOUR
1330 PHP=CAP*D(7,1)
1335 C
1340 C CALCULATE NUMBER OF ANNUAL PASSENGERS
1350 ENSP=CAP*365.
1355 C
1360 C CALCULATE TOTAL ANNUAL MILES
1370 TAM=SL*DFREQ*365.
1375 C
1380 C CALCULATE ANNUAL GROSS TON MILES
1390 GTR=((60.*SL*BUTC*365.)+(100.*SL*DFREQ*365.))

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LINKML
1395 C
1400 C CALCULATE ANNUAL CAR MILES
1410 CM=SL*BUTC*365.
1415 C
1420 C CALCULATE PEAK PERIOD HEADWAY
1430 PHD=(2*D(12,1))/PFR
1435 C
1440 C CALCULATE BASE PERIOD HEADWAY
1450 OHD=(D(11,1)-(2*D(12,1)))/OFR
1455 C
1460 C THIS SECTION CALCULATES THE NUMBER OF TRAINS NEEDED TO OPERATE
1470 C SERVICE AND THE AVERAGE NUMBER OF CARS PER TRAIN
1480 IF(D(12,1)-(TT/2)) 151,150,150
1485 150 BNTN=(TT/(2*PHD))+1.
1487 NTR=IFIX(BNTN)
1489 BNTN=BNTN-2.
1490 BNTN=BNTN+0.1*BNTN
1492 BNTN=BNTN+0.99
1494 BNTN=IFIX(BNTN)
1496 CND=NTR*2.*UCT
1498 CND=CND+0.1*CND
1500 CND=CND+0.99
1502 CND=IFIX(CND)
1504 GO TO 152
1510 151 BNTN=(D(12,1)+((OHD/PHD-1)/OHD)+(TT/(2*OHD))+1)
1530 NTR=IFIX(BNTN)
1540 BNTN=NTR-2.
1550 BNTN=BNTN+0.1*BNTN
1560 BNTN=BNTN+0.99
1570 BNTN=IFIX(BNTN)
1580 MBNTN=TT/(2*OHD)-PH/OHD
1590 MBNTN=IFIX(MBNTN)
1600 NPTR=NTR-MBNTN
1610 CND=2.*((NPTR*UCT)+(MBNTN*UOCT))
1700 CND=CND+(CND*.1)
1710 CND=CND+.99
1720 CND=IFIX(CND)
1730 GO TO 152
1735 C
1740 C THIS SECTION CALCULATES GENERAL VARIABLE COSTS
1750 152 ACTI=.1523*((100000.*BNTN)+(63000.*CND))
1760 EP=.4285*CM
1770 BS=.5247*TAM
1780 DO=.2501*TAM
1790 YAS=.2064*TAM
1800 ASPT=.1817*TAM
1810 TRC=(2.2945*TAM)+(.3047*CM)
1820 DME=(1.1469*TAM)+(.3105*CM)
1830 DMWS=(31873*SL)+(.00608*6TM)
1835 GVC=ACTI+EP+BS+DO+YAS+ASPT+TRC+DME+DMWS
1836 C
1840 C THIS SECTION CALCULATES URBAN VARIABLE COSTS
1850 UTSP=.6750*BNSP
1860 UTIL=.2321*BNSP
1870 CLEN=.1428*BNSP
1880 SMAIN=.1652*BNSP
1890 SMA=.4969*TAM
1895 UVC=UTSP+UTIL+CLEN+SMAIN+SMA
1896 C
1900 C THIS SECTION CALCULATES ALL FIXED COSTS
1910 TER=685400*SL
1920 GFC=TER
1930 SVC=100000.
1940 SFC=0.
1950 UFC=0.C
1955 C
1960 C THIS SECTION COMPUTES THE INFORMATION TO BE PRINTED AS OUTPUT
1970 UUV=6VC+UVC+SVC*D(12,NO)
1980 UUF=6FC+D(13,NO)*UFC+D(14,NO)*SFC
1990 TUUC=UUF+UUV
2000 UUVMOV=UUV-ACTI
2010 ZZ=CAP*ZSL*365.
2020 PPCUU=TUUC/ZZ
2030 PPVVV=UUV/ZZ
2040 PPVOV=UUVMOV/ZZ
2050 PH=D(12,1)*2
2060 EP=D(11,1)-PH
2065 C
2070 C THIS SECTION PRINTS THE OUTPUT

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LINKML

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2000 WRITE (21,5)
2005 WRITE (21,6)
2009 WRITE (21,41)
2009 WRITE (21,5)
2009 WRITE (21,10) ZSL
2009 WRITE (21,11) CAP
2009 WRITE (21,5)
2009 WRITE (21,8)
2009 WRITE (21,12)
2009 WRITE (21,8)
2009 WRITE (21,12)
2009 WRITE (21,8)
2009 WRITE (21,12)
2009 WRITE (21,12) PH, BP
2009 WRITE (21,12) D(1,JO), D(2,JO)
2009 WRITE (21,33) PCAP, OCAP
2009 WRITE (21,34) EPHF, BPP
2009 WRITE (21,35) D(5,KO), D(6,KO)
2009 WRITE (21,37) DFFR, DOFR
2009 WRITE (21,8)
2009 WRITE (21,15)
2009 WRITE (21,16)
2009 WRITE (21,8)
2009 WRITE (21,13)
2009 WRITE (21,14)
2009 WRITE (21,8)
2009 WRITE (21,8)
2009 WRITE (21,8)
2009 WRITE (21,35) UUF
2009 WRITE (21,35)
2009 WRITE (21,35) UUV
2009 WRITE (21,8)
2009 WRITE (21,27) TUUC
2009 WRITE (21,8)
2009 WRITE (21,29) PPCU
2009 WRITE (21,27)
2009 WRITE (21,8)
2009 WRITE (21,38) PPUV
2009 WRITE (21,18)
2009 WRITE (21,8)
2009 WRITE (21,39) PPGV
2009 WRITE (21,19)
2009 C
2009 C
2009 NO=NO-1
2009 407 CONTINUE
2009 SL=ZSL*D(4,3)
2009 405 CONTINUE
2009 CAP=CAP*D(3,3)
2009 404 CONTINUE
2009 KO=KO-1
2009 403 CONTINUE
2009 JO=JO-1
2009 402 CONTINUE
2009 STOP
2009 8 FORMAT(1H0)
2009 10 FORMAT(1H0,15X,"ONE WAY STAGE LENGTH",15X,F7.1,2X,"MILES")
2009 11 FORMAT(1H0,15X,"DAILY PASSENGER FLOW ON LINK",7X,F7.1)
2009 12 FORMAT(1H0,15X,"PEAK",11X,"EASE")
2009 13 FORMAT(1H0,5X,"ALL VALUES FOR THE PEAK PERIOD ARE THE COMBINED")
2009 14 FORMAT(1H0,5X,"TOTAL OF THE MORNING AND EVENING PEAKS")
2009 15 FORMAT(1H0,5X,"ALL OF THE ABOVE VALUES REPRESENT A TWO WAY FLOW")
2009 16 FORMAT(1H0,5X,"ON THE LINK")
2009 31 FORMAT(1H0,5X,"DURATION OF PERIOD, HOURS",19X,F7.1,8X,F7.1)
2009 32 FORMAT(1H0,5X,"LOAD FACTOR",33X,F7.1,8X,F7.1)
2009 33 FORMAT(1H0,5X,"USABLE SEATS PER TOTAL PERIOD",15X,F7.1,8X,F7.1)
2009 34 FORMAT(1H0,5X,"PASSENGER FLOW DURING PERIOD",16X,F7.1,2X,F7.1)
2009 35 FORMAT(1H0,5X,"MINIMUM ALLOWABLE FREQUENCY",17X,F7.1,2X,F7.1)
2009 36 FORMAT(1H0,5X,"ACTUAL FREQUENCY PER PERIOD",17X,F7.1,8X,F7.1)
2009 25 FORMAT(1H0,5X,"ANNUAL FIXED COST",14X,F15.2)
2009 26 FORMAT(1H0,5X,"ANNUAL VARIABLE COST",11X,F15.2)
2009 27 FORMAT(1H0,5X,"ANNUAL TOTAL COST",14X,F15.2)
2009 29 FORMAT(1H0,5X,"CCST PER PASSENGER MILE",9X,F13.4)
2009 17 FORMAT(1H0,5X,"TOTAL COST")
2009 38 FORMAT(1H0,5X,"CCST PER PASSENGER MILE",9X,F13.4)
2009 39 FORMAT(1H0,5X,"VARIABLE COST")
2009 39 FORMAT(1H0,5X,"CCST PER PASSENGER MILE",9X,F13.4)
2009 41 FORMAT(1H0,5X,"VARIABLE COST MINUS VEHICLES")
2009 50 FORMAT(1H0,5X,"HIGH SPEED RAIL")
2009 2465 END
```

## Computer Program Input

The data file used with the LINKML program is called VTOL and consists of an array of 14 rows and 8 columns (8 F 10.2 format), which is referred to as array D (I,J). The following entries are made from each row.

Row 1 and 2: These lines specify the base period and peak period maximum load factors to be used in the analysis. At least one pair of load factors must be specified, but the program can analyze up to 7 pairs of load factors.

Note: Any columns not being used to specify load factors may be left blank.

Row 3: This row specifies the daily two-way passenger flow on the link. It is assumed that passenger flows are equal in both directions on the link.

Row 4: This row specifies the one-way, air statute mile stage length on the link. For rail, a circuitry factor computed by the program calculates rail distances from the given air distance. If actual stage lengths are used, the circuitry factors should be set at zero.

Row 5 and 6: These rows specify the frequency, called here minimum allowable frequency, on which vehicles will operate in the peak and base periods. Like Rows 1 and 2, these rows operate as a pair. Row 5 specifies the peak period minimum allowable frequency, Row 6 specifies the base period minimum allowable frequency. Minimum allowable frequency is defined as that number of departures, in both directions on the link, which must be performed, to conform to some standard or level of service. At least one pair of frequencies must be given, but up to seven pairs of frequencies can be read by the program.

Row 7: Row 7 specifies the fraction of daily passengers on the link in each peak hour. For example, if there are 2000 daily passengers, and in each peak hour there are 200 passengers on the link, then the fraction of daily

passengers on the link in each peak hour is  $1/10$ , or .10.

Row 8: This row specifies the maximum number of cars per train. If the number of passengers increases and equals this number, a new train is started.

Row 9: Row 9 is used to show seating capacities of alternative types of railroad cars. This row accommodates two different seating capacities. For instance, if level of service requirements dictate a coach car and snack coach car to be added alternately to the train consist, then the capacity of the coach car would be entered in the first field, the capacity of the snack-coach in the second field. The program develops the train consist by selecting each seating arrangement alternately, for example, snack-coach, coach, snack-coach, etc. Obviously, alternative seating pairs could be used; coach and parlor, parlor and snack-coach, etc.

Row 10: Row 10 does not apply to the rail mode. For the rail mode enter 1.0 in columns 1-3 of this row.

Row 11: Row 11 specifies the number of hours in a 24 hour day the system is in operation. Time starts when the first vehicle departs and ends when the last vehicle departs.

Row 12: Row 12 specifies the number of hours in each peak period. The morning and evening peaks are assumed to have the same duration. This row shows the number of hours out of the total hours of operation that are in each peak period.

Row 13 and 14: Rows 13 and 14 specify the number of intermediate plus endpoint stops on the link. At least one pair of terminal combinations must be specified, but the program will analyze up to seven combinations; at least the two endpoints must be specified.

### Computer Program Output

The computer output calculated by the LINKML program, is listed under the heading "RAILCOST," which gives annual cost and costs per passenger mile for capacities 500-3000 daily passengers (in 500 passenger increments) and for stage lengths 100-300 miles (in 100 mile increments).

500.00  
100.00  
18.00  
12.00



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COSTRAIL

ONE WAY STAGE LENGTH  
DAILY PASSENGER FLOW ON LINK

HIGH SPEED RAIL

100.0 MILES  
500.0

PEAK

4.0  
409.6  
200.0  
8.0  
8.0

BASE

12.0  
384.0  
300.0  
12.0  
12.0

DURATION OF PERIOD, HOURS

LOAD FACTOR

USABLE SEATS PER TOTAL PERIOD

PASSENGER FLOW DURING PERIOD

MINIMUM ALLOWABLE FREQUENCY

ACTUAL FREQUENCY PER PERIOD

ALL OF THE ABOVE VALUES REPRESENT A TWO WAY FLOW  
ON THE LINK

ALL VALUES FOR THE PEAK PERIOD ARE THE COMBINED  
TOTAL OF THE MORNING AND EVENING PEAKS

ANNUAL FIXED COST 78135600.00

ANNUAL VARIABLE COST 11537775.63

ANNUAL TOTAL COST 89673375.00

COST PER PASSENGER MILE 4.9136

TOTAL COST .6322

COST PER PASSENGER MILE .5754

VARIABLE COST MINUS VEHICLES